7-17-1969

Drought in the St. Clair Region.

Ronald C. A. Johnson
University of Windsor

DROUGHT IN THE ST. CLAIR REGION

By

RONALD C. A. JOHNSON

A THESIS

Undertaken as partial fulfillment
of requirements for the M. A. degree
at the University of Windsor

Windsor, Ontario

1969

ABSTRACT

The St. Clair Region, although situated in a productive and humid agricultural area, suffers from moisture deficiency during the growing season great enough to decrease crop yields. The frequency and severity of such moisture deficiency is important to determine the loss to farmers because of reduced yields and if irrigation would be a practical solution.

Monthly water balances were computed for the 12 climatological stations within the Region based on available record and soil type. The results were then statistically analysed to determine how severe drought is within the area.

Farmers were interviewed to determine to what extent they perceived the danger of drought, and their reaction to drought conditions.

The results showed a north to south variation in both precipitation and potential evapotranspiration. This factor combined with different types of soils resulted in large variations of moisture deficiency throughout the Region. Although the farmers recognized the danger of drought, their reaction was quite different depending upon type of farm and expected increased yields.

Supplemental irrigation would greatly increase crop yields in the Region. Whether irrigation would be practical depends upon the increased value of the crop compared to the cost of irrigation.

ACKNOWLEDGEMENTS

Expressions of gratitude must be given to the following persons and agencies for their kind assistance:

M. E. Sanderson, Department of Geography,
University of Windsor

I. Stebelsky, Department of Geography,
University of Windsor

Rev. J. F. Callaghan, Department of Economics,
University of Windsor

J. R. Mather, C. W. Thornthwaite Associates,
Centerton, New Jersey,

J. M. Fulton and staff, Agricultural Research Station,
Harrow, Ontario.

Francine, my wife and typist.

TABLE OF CONTENTS

Page

ABSTRACT ii

ACKNOWLEDGMENT iii

LIST OF TABLES v

LIST OF ILLUSTRATIONS vi

Chapter

I. INTRODUCTION 1

Definitions of Drought
Four Types of Drought
Results of Irrigation in Humid Areas

II. METHODOLOGY 8

Water Balance
Soils

III. ANALYSIS OF DATA 23

Precipitation
Potential Evapotranspiration
Deficiency During the Growing Season
Monthly Deficiency

IV. PERCEPTION OF THE DROUGHT HAZARD 58

The Sample
Area I
Area II
Summary

V. CONCLUSIONS 70

APPENDIX A 72

APPENDIX B 75

BIBLIOGRAPHY 77

LIST OF TABLES

Table		Page
1.	Average Water Balance Harrow, Ontario	11
2.	Climatological Stations in the St. Clair Region	12
3.	Water Holding Capacities with Different Combinations of Soil and Vegetation	14
4.	Soils of the St. Clair Region	15-18
5.	Total Acreage of Soils in the St. Clair Region	19
6.	Variations in Moisture Deficiency During the Growing Season	39-40
7.	Variations in Moisture Deficiency by Month	49-55
8.	Advantages and Disadvantages in Cash Crop Areas	60
9.	Comparison of 1965 Moisture Deficiency to Average Conditions	65
10.	Advantages and Disadvantages in Fruit and Vegetable Areas	66

LIST OF ILLUSTRATIONS

Figure		Page
1.	The St. Clair Region	(in folio)
2.	Modified Soils Map	(in folio)
3.	Water Holding Capacities	(in folio)
4.	Average Precipitation, Growing Season	24
5.	Precipitation, Growing Season, 1953	24
6.	Maximum Precipitation Expected	26
7.	Minimum Precipitation Expected	26
8.	Precipitation and Potential Evapotranspiration Growing Season 1940-67	27-29
9.	Average Potential Evapotranspiration Growing Season	31
10.	Potential Evapotranspiration, Growing Season, 1962	31
11.	Maximum Potential Evapotranspiration Expected	32
12.	Minimum Potential Evapotranspiration Expected	32
13.	Average Water Balances, 3.0 inch Water Holding Capacity	34
14.	Average Water Balances, 6.0 inch Water Holding Capacity	35
15.	Average Water Balances, 8.0 inch Water Holding Capacity	36
16.	Variation of Deficiency, Growing Season 1940-1960. . . .	38
17.	Average Water Deficiency Growing Season	42
18.	Average Water Deficiency (May)	43

Figure		Page

19. Average Water Deficiency (June) 44

20. Average Water Deficiency (July) 45

21. Average Water Deficiency (August) 46

22. Average Water Deficiency (September) 47

23. Study Area 1 62

24. Study Area II 64

CHAPTER 1

INTRODUCTION

The St. Clair Region, considered in the present study as Essex, Kent and Lambton counties, lies in one of the most productive agricultural regions in Canada. Although possessing only 11.3 per cent of the arable land in Ontario the St. Clair Region produces 15.7 per cent of all principal field crops and 30.9 per cent of all fruits and vegetables. The three county area dominates the Ontario production of soybeans (86%), shelled corn (45%), winter wheat (39%) and barley (36%). The importance of the area is further emphasized by the figures for the production of fruits and vegetables. Of the total Ontario production of cantaloupes, tomatoes, pepper, beets, and onions (market), Essex and Kent counties[1] produce 95, 72, 72, 57, and 50 per cent respectively.

An area so dependent upon agricultural production will be greatly affected economically by any climatic condition that reduces crop yield. Experiments at Harrow[2] have shown that seasonal rainfall is almost always insufficient to allow maximum crop production.

The present study of moisture deficiency within the St. Clair Region will analyse the frequency and severity of water shortages within this area. Statistics were calculated with the aid of a computer programme from the Thornthwaite Laboratory of Climatology, New Jersey, which computes the monthly water balance, (Appendix A).

The monthly deficiencies will be analysed to show maximum and minimum deficiencies expected, frequencies of varying degrees of deficiency and averages for both monthly and seasonal time periods.

The farmers perception of the danger of drought is also very important in determining how they will react to the situation. By use of a questionnaire an attempt was made to discover how great the farmers felt the danger of water deficiency was to crop production and their reaction to the situation.

Definitions of Drought

Drought is not an easily defined term. How severe must a water shortage be before it is classed as a drought? How can the dividing line between a moderate and severe drought be determined? These are questions that have perplexed climatologists and agriculturalists for many years.

Drought has most often been defined in terms of the amount of rainfall below average conditions, or a period of consecutive days without rainfall. The United States weather bureau considers drought to exist whenever the rainfall for a period of 21 days or longer is 30 per cent of the average.[3] The British Rainfall Organization defines "absolute" drought as a period of 15 or more consecutive days without rain, whereas a partial drought occurs after a period of 28 days with rainfall averaging not more than one hundredth of an inch a day. Russian meteorologists define drought as a period of ten days with a total rainfall not exceeding a fifth of an inch.

Other attempts at a definition of drought have been less quantitative. Wayne C. Palmer gives two such definitions "Drought . . . a relatively temporary departure of the climate from the normal or average climate toward aridity."[4] and " . . . a prolonged and abnormal moisture deficiency."[5] H. E. Thomas gives a more complicated definition:

> drought (is) . . . a meteorological phenomenon which occurs during a period when precipitation is significantly less than the long term average and when this deficiency is great enough and continues long enough to affect mankind.[6]

Drought has been defined in terms of its effects on vegetation. One such definition by Barger and Thom considered drought to occur after:

> a specific period of time during which the total amount of rainfall recorded at a station is deficient to the extent that, more often than not, the yield falls below normal for the county in which the station is located.[7]

Tannehill more simply defines drought as " . . . a period of deficient rainfall that is seriously injurious to vegetation."[8]

All of the above definitions have drawbacks. The definitions offered by the United States weather bureau, the British Rainfall Organization and the Russian weather bureau all define drought in terms of rainfall alone. Drought obviously cannot be defined in this manner, for such a definition would fail to take into consideration the amount of water that was actually needed. For example, the effect of 15 days without rainfall would be much greater if the soil were relatively dry at the beginning of the 15 day period than if it had been saturated with water.

The definitions of Palmer and Thomas, based on the events and the end result of drought, fail to give a quantitative measure whereby the intensity, duration or seriousness of a drought can be measured. What actually constitutes a "prolonged and abnormal moisture deficiency"?

The definition of Burger and Thom is closer to a definition of agricultural drought, but it too is unsatisfactory. A crude measure of rainfall is not sufficient for accurate prediction of its effect upon crop production. More precisely drought begins when the crop cover can no longer draw upon the soil moisture rapidly enough to replace that lost by evapotranspiration, with the result that the actual evapotranspiration becomes less than the potential evapotranspiration. This will not necessarily begin on the day that rain ceases but will depend upon the potential evapotranspiration and level of soil moisture.

Four Types of Drought

There are four basic types of drought. The first is permanent drought. This occurs in the driest climates where there is always a water deficit, vegetation is sparse and agriculture is only possible by extensive irrigation. The second is seasonal drought which occurs in areas with definite wet and dry seasons. Planting must be adjusted so that the crop will grow through the wet season. Crops grown at other times of the year must have irrigation. The third kind, contingent drought, results from the fact that rainfall is irregular. Contingent drought is not limited to any special time period but is more probable during the summer when potential evapotranspiration is high. Contingent droughts are most commonly associated with subhumid and humid climates and result in brief and irregular water shortages. A fourth type of drought has been receiving increasingly greater attention. The "invisible drought", as it is sometimes called, occurs when summer rainfall is insufficient to restore the water lost by evaporation and transpiration, with the result that the crop yield is greatly reduced. When water is added by irrigation to overcome this deficiency the crop yields can be significantly increased.

The question of invisible drought and its effect upon crop yield is closely connected with two schools of thought that have developed over the question of moisture stress on plants. The first, led by F. J. Viehmeyer,[9] holds the view that water is rapidly available to plants over the range from field capacity almost to the permanent wilting point; that is, the actual evapotranspiration equals the potential evapotranspiration until all available water is gone. The second school of thought led by P. J. Kramer[10] asserts that water becomes progressively less available as the water content of the soil decreases, with the result that the plants begin to suffer from water deficits long before the water content reaches the permanent wilting point. Thus Kramer's view is that the actual evapotranspiration equals a decreasing fraction of the potential evapotranspiration as the water level decreases.

The view held by Kramer is the generally accepted theory today. G. Stanhill[11] found, when studying eighty papers on soil moisture-crop yield experiments, that over 80 per cent showed that plant growth was affected by differences in available water: as soil moisture decreased, plant growth was retarded. Invisible drought, therefore, seems to be a definite factor in crop production.

Results of Irrigation in Humid Areas

The humid eastern part of North America, which includes Ontario and eastern United States, generally has sufficient rainfall to support the production of crops and pastures. Supplemental irrigation has been used in the east to overcome the poor distribution of rainfall during the growing season. The purpose of such irrigation has been to improve the crop production, rather than enable the introduction of new crops as has been the case in Western United States. Researchers have found that supplemental irrigation results in higher yields and better quality products by guarding against the effect of droughts.

Experiments at Athens, Georgia[12] showed that supplemental irrigation increased corn yields by 6 bushels per acre in years of nearly adequate rainfall; in years of drought, however, the yields were increased by 64 bushels per acre. Similarly E. E. Hartwig, P. Grissom, and W. A. Raney[13] found that supplemental irrigation of soybeans in the humid east increased yields by 5 to 7 bushels per acre on sandy loam soil and 10 bushels per acre on clay soil. Thus supplemental irrigation allowed maximum production by insuring that the plants were not deprived of water at any time during their growth.

REFERENCES

[1]Agricultural statistics were obtained from _Agricultural Statistics for Ontario, 1967_, Ontario Department of Agriculture and Food (Toronto, 1968). Separate statistics are not available for Lambton County.

[2]J. M. Fulton, "Soil Moisture for Crop Production," _Canada Agriculture_, (Winter, 1967), 1.

[3]I. R. Tannehill, _Drought; Its Causes and Effects_ (Princeton, 1947), p. 37.

[4]Wayne C. Palmer, _Weekly Weather and Crop Bulletin_, U. S. Weather Bureau, XIIV, No. 1a (January 10, 1957), 1.

[5]Wayne C. Palmer, "Meteorological Drought," _U. S. Weather Bureau Research Paper No. 45._ (February, 1965), 2.

[6]H. E. Thomas, "General Summary of Effects of Drought in the Southwest," _Geological Survey Professional Paper_ 372-H. (Washington: U. S. Government Printing Office, 1963), 1.

[7]Gerald L. Barger and H. C. S. Thom, "A Method for Characterizing Drought Intensity in Iowa," _Agronomy Journal_, XLI (1949), 13-19.

[8]Tannehill, p. 39.

[9]F. J. Veihmeyer and A. H. Hendrickson, "Does Transpiration Decrease as the Soil Moisture Decreases?" _Transactions of the American Geophysical Union_, XXXVI (1955), 425-428.

[10]P. J. Kramer, "The Role of Water in the Physiology of Plants," _Advances in Agronomy_, II, (1959), 51-70.

[11]G. Stanhill, "The Effect of Differences in Soil Moisture Status on Plant Growth: A Review and Evaluation," _Soil Science_, LXXXIV (1957), 205-214.

[12]H. F. Rhoades and L. B. Nelson, "Growing 100-Bushel Corn with Irrigation," in _Water, The Yearbook of Agriculture_, ed. Alfred Stefferud (Washington, U. S. Department of Agriculture, 1955), p. 395.

[13]D. M. Whitt and C. H. M. Van Bavel "Irrigation of Tobacco, Peanuts and Soybeans," in _Water, The Yearbook of Agriculture_, ed. Algred Stefferud (Washington, U. S. Department of Agriculture, 1955), p. 380.

CHAPTER II

METHODOLOGY

Water Balance

In choosing a method for calculating deficiency it was necessary to find a system that could be used with the available data and one that gave a fairly accurate measure of deficiency. Several such methods are available. Two of the most common, those introduced by Thornthwaite and Penman, employ similar approaches. Both methods are based on computing potential evapotranspiration, computing actual evapotranspiration as a function of potential evapotranspiration and soil moisture, and a system of budgeting soil moisture.

Penman's method, although more theoretically sound than Thornthwaite's, has the difficulty of requiring parameters that are neither easily measured nor easily available. The method chosen for this study, the Thornthwaite water balance model, estimates monthly soil moisture and deficiency with knowledge of only average temperature, precipitation and type of soil. Such data are available for the St. Clair Region from the *Monthly Record* published by the Department of Transport, and the *Ontario Soil Surveys* published by the Ontario Department of Agriculture and Food.

Many researchers have found a high correlation between measured potential evapotranspiration and the Thornthwaite estimates. Smith[1] in Trinidad found the Thornthwaite estimates to be as reliable as

Penman's. Sanderson[2] at Windsor and Toronto found a very high correlation coefficient of r=.93 for measured and computed monthly estimates.

Pelton, King and Tanner[3] examined the use of air temperature to derive potential evapotranspiration. Their criticisms are based on the fact that potential evapotranspiration is dependent upon net radiation, while air temperature is not a true measure of energy available for evapotranspiration. Thornthwaite and Mather, in justifying the use of mean temperature, found that mean temperature could serve as an index of potential evapotranspiration because there is on a monthly basis a fixed relationship between the net radiation used for heating and that used for evaporation and that this ratio varies with temperature.[4]

It is known that as radiation (the energy needed for evaporation) increases and decreases during the year, the temperature will vary similarly, although there will be a lag effect. Pelton, King and Tanner at Madison, Wisconsin found that the thermal lag is least when both temperature and net radiation are maximum which occurs in July. This lag effect will cause an underestimation of potential evapotranspiration and deficiency in May and June, fairly accurate estimates in July, and an overestimation in August and September.[5]

Monthly figures were used rather than shorter time periods because the accuracy of the method decreases with shorter periods of time. Pistor found that the longer periods of measurement yielded more accurate estimates of actual evapotranspiration. When correlating measured and computed actual evapotranspiration on a one-day, five-day, ten-day and monthly time periods in Harrow, he found a correlation coefficient of r=.349, .784, .797, .939 respectively.[6]

Table 1 shows the average water balance for Harrow. The Thornthwaite water balance uses potential evapotranspiration (P. E. line 3), defined by Thornthwaite as the amount of water that would evaporate and transpire from a vegetated surface if available in optimum quantities at all times. The crop, however, does not always have the moisture available to evaporate and transpire at the potential rate, but will use less water as the soil moisture (line 7) decreases. The amount actually used by the plant is the actual evapotranspiration (AE line 9). The difference between the potential and the actual evapotranspiration represents the amount of water which was required by the plant cover, but was not available, that is, the deficiency (line 10). This is the "invisible drought," and the greater the deficiency during the growing season, the greater the reduction in yield.

Twelve climatic stations are located within the St. Clair Region with records varying from 9 to 28 years (see table 2). Although many more stations would be desireable, their even spacing throughout the region (figure 1 in folio)[7] provides this area with one of the most comprehensive coverages in Canada.

Soils

The use of the Thornthwaite water balance requires a knowledge of the moisture holding capacity of the soil. For this, it is necessary to know the root depths and the texture of the soil. These two factors will give the water holding capacity for any combination of soil and crop. Clay soil, for example, holds approximately 3.6 inches of water per foot of soil while allowing the roots of a moderately deep rooted crop like corn to penetrate 1.67 feet, making 6.0 inches of water

TABLE 1

AVERAGE WATER BALANCE
HARROW ONTARIO

(Water Holding Capacity of 6.0 Inches)*

	J	F	M	A	M	J	J	A	S	O	N	D	Year
T F**	25.6	26.4	33.5	45.9	57.4	68.3	72.7	71.3	63.8	52.8	39.7	28.8	48.9
Unadj PE	0	0	0	.04	.09	.13	.15	.14	.11	.07	.02	0	29.01
PE	0	0	0	1.34	3.40	4.95	5.76	5.00	3.43	2.00	.49	0	26.37
P	2.26	2.16	2.32	2.68	2.68	3.09	2.52	2.61	2.25	2.21	2.11	2.12	
P-PE	2.26	2.16	2.32	1.34	-.72	-1.86	-3.24	-2.39	-1.18	.21	1.62	2.12	
Acc Pot WL					-.72	-2.58	-5.82	-8.21	-9.39				
ST	7.41	9.57	6.00	6.00	5.31	3.87	2.23	1.48	1.20	1.41	3.03	5.15	
ΔST	.85	0	0	0	-.69	-1.44	-1.64	-.75	-.28	.21	1.62	2.12	
AE	0	0	0	1.34	3.37	4.53	4.16	3.36	2.53	2.00	.49	0	21.78
D	0	0	0	0	.03	.42	1.60	1.64	.90	0	0	0	4.59
S	0	0	5.89	1.34	0	0	0	0	0	0	0	0	7.23
RO	0	0	2.95	2.15	1.07	.54	.27	.14	.07	.03	.02	.01	7.23

* All values except T are in inches.

** Abbreviations: T, mean air temperature; Unadj PE, unadjusted potential evapotranspiration; PE, potential evapotranspiration; P, precipitation; P-PE, precipitation minus the potential evapotranspiration; Acc Pot WL, accumulated potential water loss (accumulated sum of the negative P-PE values); ST, storage; ΔST, change in soil moisture; AE, actual evapotranspiration; D, moisture deficiency; S, moisture surplus; RO, water runoff.

TABLE 2

CLIMATOLOGICAL STATIONS
IN THE ST. CLAIR REGION

Station	Years of Record	Station	Years of Record
Camlachie	9	Pelee Island	27
Chatham	28	Ridgetown	28
Forest+	25	Sarnia	19
Harrow	28	Wallaceburg+	22
Leamington	28	Windsor	27
Oil Springs*+	13	Woodslee	21

* Includes Records for Oil City 1954-59.

\+ No longer in operation.

available to the crop when the soil is at field capacity.[8]

The Laboratory of Climatology in Centerton, New Jersey has grouped the number of soil types into 5 major classes: fine sand, fine sandy loam, silt loam, clay loam and clay, each having unique water holding capacity (see table 3). For the purposes of this study the soils of the St. Clair Region have also been grouped into the same five categories, as shown in Table 4.

Soil surveys and maps of Essex, Kent and Lambton Counties were obtained from the Ontario Department of Agriculture and the soils shown were grouped into the above five texture categories on the basis of the percentage of clay, silt or sand in each type of soil. Figure 2 (in folio) shows the five soil classes of the St. Clair Region.

Table 5 summarizes the percentages of the various soils in the St. Clair Region by county. The most predominant type of soil is clay (59.2%). The remaining soils are much less prevalent in the area: fine sandy loam (15.1%), clay loam (8.8%), silt loam (6.3%), fine sand (5.9%) and miscellaneous soils (4.6%). The miscellaneous soils have not been included in the breakdown of water holding capacities (see figure 3 in folio) because they are made up of various soils which are hard to define e.g. bottomland, or are not fully developed soils e.g. marsh.[9] These soils appear in only small patches throughout the region except for areas in southwest Essex County, Point Pelee, Rondeau, and northeast Lambton County. In other areas they are found mainly along rivers or poorly drained lowlands. Because of this scattered nature, diversity of soil type and the relatively small percentage the miscellaneous soils covering the area, they have been omitted from the deficiency studies.

TABLE 3

WATER HOLDING CAPACITIES WITH DIFFERENT COMBINATIONS OF SOIL AND VEGETATION

Soil Type	Available Water IN/FT	Root Zone FT	Applicable Soil Moisture Retention Table IN
Shallow-Rooted Crops (Spinach, Peas, Beets, Carrots, Etc.)			
Fine Sand	1.2	1.67	2.0
Fine Sandy Loam	1.8	1.67	3.0
Silt Loam	2.4	2.08	5.0
Clay Loam	3.0	1.33	4.0
Clay	3.6	.83	3.0
Moderately Deep-Rooted Crops (Corn, Tobacco, Cereal Grains)			
Fine Sand	1.2	2.50	3.0
Fine Sandy Loam	1.8	3.33	6.0
Silt Loam	2.4	3.33	8.0
Clay Loam	3.0	2.67	8.0
Clay	3.6	1.67	6.0
Deep-Rooted Crops (Alfalfa, Pastures, Shrubs)			
Fine Sand	1.2	3.33	4.0
Fine Sandy Loam	1.8	3.33	6.0
Silt Loam	2.4	4.17	10.0
Clay Loam	3.0	3.33	10.0
Clay	3.6	2.22	8.0
Orchards			
Fine Sand	1.2	5.00	6.0
Fine Sandy Loam	1.8	5.55	10.0
Silt Loam	2.4	5.00	12.0
Clay Loam	3.0	3.33	10.0
Clay	3.6	2.22	8.0
Closed Mature Forest			
Fine Sand	1.2	8.33	10.0
Fine Sandy Loam	1.8	6.66	12.0
Silt Loam	2.4	6.66	16.0
Clay Loam	3.0	5.33	16.0
Clay	3.6	3.90	14.0

Source: C. W. Thornthwaite and J. R. Mather, "Instructions and Tables for Computing Potential Evapotranspiration" Publications in Climatology, Laboratory of Climatology, X no. 3 (New Jersey, 1957), 244.

TABLE 4

SOILS OF THE ST. CLAIR REGION

County	Name of Soil	Acreage	Class (By Thornthwaite Laboratory)	Per Cent of County Total
Essex	Brookston Clay	250,000		
	Toledo Clay	17,500		
	Clyde Clay	2,500		
	Jeddo Clay	3,500	Clay	65.8
	Caistor Clay	13,500		
	Perth Clay	9,000		
	Total Clay	301,000		
	Perth Clay Loam	8,000		
	Castor Clay Loam	2,500		
	Brookston Clay Loam	30,000	Clay Loam	10.8
	Burford Loam	3,700		
	Burford Loam-Shallow	5,300		
	Total Clay Loam	49,500		
	Toledo Silt Loam	1,000		
	Harrow Loam	4,000		
	Farmington Loam	2,000	Silt Loam	3.7
	Parkhill Loam	5,000		
	Parkhill Loam Red Sand Spot Phase	5,000		
	Total Silt Loam	17,000		
	Tuscola Fine Sandy Loam	6,000		
	Colwood Fine Sandy Loam	7,000		
	Harrow Sandy Loam	3,500		
	Fox Sandy Loam	5,300		
	Berrien Sandy Loam	16,000	Fine Sandy Loam	13.1
	Caistor Sand Spot Phase	1,500		
	Brookston Clay Sand Spot Phase	18,000		
	Wauseon Sandy Loam	3,000		
	Total Fine Sandy Loam	60,300		

TABLE 4--Continued

County	Name of Soil	Acreage	Class (By Thornthwaite Laboratory)	Per Cent of County Total
Essex	Granby Sand	1,000		
	Berrien Sand	8,000		
	Plainfield Sand	1,700	Fine Sand	2.8
	Eastport Sand	2,500		
	Total Fine Sand	13,200		
	Bottom Land	7,300		
	Marsh	7,000	Miscellaneous	3.5
	Muck	1,700		
	Total Miscellaneous	16,000		
Kent	Haldimand Clay	2,000		
	Napanee Clay	5,000		
	Brookston Clay	177,000	Clay	32.0
	Clyde Clay	35,000		
	Total Clay	189,000		
	Miami Clay Loam	44,000		
	Miami Clay Loam (Gravelly Phase)	5,000		
	Canover Clay Loam	8,000	Clay Loam	17.6
	Canover Loam	2,000		
	Thames Clay Loam	18,000		
	Brookston Clay Loam	31,000		
	Total Clay Loam	104,000		
	Haldimand Loam	16,000		
	Beverly Loam	10,000		
	Brookston Silt Loam	37,000	Silt Loam	14.0
	Brookston Loam	10,000		
	Clyde Silt Loam	10,000		
	Total Silt Loam	83,000		

TABLE 4--Continued

County	Name of Soil	Acreage	Class (By Thornthwaite Laboratory)	Per Cent of County Total
Kent	Fox Sandy Loam	400		
	Fox Gravelly Loam	17,000		
	Berrien Sandy Loam	46,000		
	Beverly Fine Sandy Loam	9,000	Fine Sandy	
	Brookston Sandy Loam	51,000	Loam	24.3
	Clyde Loam	17,000		
	Gilford Gravelly Loam	2,000		
	Brady Gravelly Loam	1,000		
	Total Sandy Loam	143,400		
	Plainfield Sand	300		
	Berrien Sand	53,000	Fine Sand	10.5
	Granby Sand	9,000		
	Total Fine Sand	62,300		
	Muck	7,000		
	Bottom Land	700	Miscellaneous	1.3
	Eroded	400		
	Total Miscellaneous	8,100		
Lambton	Huron Clay	19,100		
	Perth Clay	137,300		
	Brookston Clay	308,300		
	Caistor Clay	69,100		
	Toledo Clay	300		
	Clyde Clay	1,900	Clay	77.1
	Blackwell Clay	8,600		
	Brookston and Berrien Complex	4,700		
	Perth and Berrien Complex	1,700		
	Total Clay	559,000		
	Caistor and Berrien Mixture	1,900		
	Toledo Clay Loam	1,200	Clay Loam	0.4
	Total Clay Loam	3,100		

TABLE 4--Continued

County	Name of Soil	Acreage	Class (By Thornthwaite Laboratory)	Per cent of County Total
Lambton	Lambton Silt Loam	11,400		
	Shashawandah Loam	500	Silt Loam	1.6
	Gilford Loam	100		
	Total Silt Loam	12,000		
	Colwood Fine Sandy Loam	15,300		
	Fox Sandy Loam	4,700		
	Brady Sandy Loam	7,800		
	Granby Sandy Loam	1,800		
	Berrien Sandy Loam	7,100	Fine Sandy	
	Guelph Loam	500	Loam	8.7
	Brisbane Loam	13,600		
	Burford Loam	8,000		
	Brady and Brookston Mixture	4,800		
	Total Sand Loam	63,600		
	Plainfield Sand	15,900		
	Brady Sand	10,700		
	Eastport Sand	2,400	Fine Sand	4.0
	Berrien Sand	100		
	Total Sand	29,100		
	Muck	4,500		
	Peat	900		
	Marsh	16,500	Miscellaneous	7.9
	Bottomland	35,900		
	Total Miscellaneous	57,800		

TABLE 5

TOTAL ACREAGE OF SOILS
IN THE ST. CLAIR REGION

County	Clay	Clay Loam	Silt Loam	Fine Sandy Loam	Fine Sand	Miscellaneous	Totals
Essex	301,000	49,500	17,000	60,300	13,200	16,000	457,000
Kent	189,000	104,000	83,000	143,400	62,300	8,100	589,800
Lambton	559,000	3,100	12,000	63,600	29,100	57,800	724,700
Total Acreage	1,049,000	156,100	112,000	267,300	104,600	81,900	1,770,900
Percent of each Soil Type in the Region	59.2	8.8	6.3	15.1	5.9	4.6	99.9

The clay soils are most prominent in Lambton and Essex counties, covering 77% and 66% of the area respectively. In Lambton the clay soils cover all the area except near Sarnia, the northeast section, near Port Lambton, along the east county boundary and a narrow band of sand loam stretching from Thedford to Wyoming. In Essex County clay is predominant in the interior of the county with various other soils along the shoreline. Large areas of non-clay soils can be found around Leamington, Windsor and the area from east of Kingsville to west of Harrow. In Kent County the only large area of clay is in the southwest section.

The various loam soils cover 30.2 per cent of the total area of the St. Clair Region. Clay loam is insignificant in Lambton County (0.4%). Large patches can be found around Windsor, Malden Township and Kingsville in Essex County and near Ridgetown, along Highway No. 2 east of Chatham in Kent County. Only small amounts of silt loam can be found in Essex and Lambton Counties, 3.7 and 1.6 per cent respectively, with the concentrations being at Harrow, northwest of Leamington and around Watford. Large areas of silt loam can be found in Kent County especially south of Wallaceburg and south and east of Chatham. The largest loam soil is the fine sandy loam, covering 15.1 per cent of the region's acreage. This soil is found in patches throughout the region.

A large concentration of sandy soils is found in northeast Kent and southeast Lambton as well as along the shoreline of Lambton County from Port Frank to Grand Bend. Small patches are also found near Harrow and Leamington.

In the present paper only one type of crop, with moderately deep roots e.g. corn and wheat, has been analyzed. This has been done since these crops are the most important in the area. Thus the maps and tables that follow apply to moderately deep-rooted crops only. Additional maps would be necessary to study drought in shallow-rooted crops, deep-rooted crops or orchards.

For the climatic model what is required is not a map of soil types, but water holding capacities. Although the region has been divided into five basic soil types, for moderately deep-rooted crops, only three different water holding capacities result, using the Laboratory of Climatology figures. The water holding capacity is the product of the available water per foot of soil and the root zone. For example, fine sandy loam, with much less available water per foot of soil than clay (1.8 and 3.6 inches respectively,), has the same water holding capacity as clay because the root zone of fine sandy loam is much deeper (see Table 3).

In the St. Clair Region 74 per cent of the land has a water holding capacity of 6.0 inches, 15 per cent 8.0 inches and 6 per cent 3.0 inches.[10]

REFERENCES

[1]G. W. Smith, "The Determination of Soil Moisture Under a Permanent Grass Cover," Journal of Geophysical Research, LXIV (1959), 477-483.

[2]M. E. Sanderson, "Observations of Potential Evapotranspiration at Windsor, "Publications in Climatology, VII (1954), 91-93.

[3]W. L. Pelton, K. M. King and C. B. Tanner, "An Evaluation of the Thornthwaite and Mean Temperature Methods for Determining Potential Evapotranspiration," Agronomy Journal, LII (1960), 387-395.

[4]C. W. Thornthwaite and J. R. Mather, "The Water Balance," Publications in Climatology, VIII (1955), 1-86.

[5]Pelton, King and Tanner, pp. 388-90.

[6]Pistor, A Climatological Approach to Irrigation Scheduling: A Comparison of Three Methods of Computing Water Use (University of Windsor, 1967), p. 43.

[7]Maps 1 to 3 (in folio) are of the same scale and serve the purpose of locating more exactly where the various soils and water holding capacities are by means of overlays.

[8]C. W. Thornthwaite and J. R. Mather, "Instructions and Tables for Computing Potential Evapotranspiration and the Water Balance, "Publications in Climatology, X (1956), 244.

[9]Miscellaneous soils form only a minor part of the soils in the St. Clair Region. Although some of these soils are quite productive agriculturally, they vary greatly in water holding capacity, making it impractical to include them in the study.

[10]The 6.0 inch water holding capacities occur on fine sandy loam and clay soils, the 8.0 inch water holding capacities on silt loam and clay loam soils and the 3.0 inch water holding capacities on fine sand soils.

CHAPTER III

ANALYSIS OF DATA

Precipitation

Figure 4 shows the average precipitation[1] for the growing season[2] in the St. Clair Region. The average precipitation ranges from less than 14.0 inches at Harrow and Camlachie, to over 16.0 inches at Forest. When the map of average growing season precipitation is compared to a specific year, vast differences can be seen. Whereas Figure 4 shows a variation of only 2 inches in the area, Figure 5 depicting the 1953 precipitation indicates strong spatial variation. Figure 5 shows a definite decrease in precipitation from north to south, with pockets of high precipitation around Windsor and Pelee Island. The 1953 figures show a very large variation in precipitation of greater than 12 inches, with a low near Harrow of less than 8 inches and a high near Camlachie and Forest of greater than 20 inches. Drastic variations in precipitation can occur in a relatively small and uniform area such as the St. Clair Region.

Of interest to farmers is the maximum and minimum precipitation that can be expected in any given area, and the chances of such a situation occuring. To find this the standard deviations of the growing season precipitation for all the stations were found.[4]

Figure 6 shows the maximum precipitation expected. This was obtained by plotting two standard deviations above the mean, that is

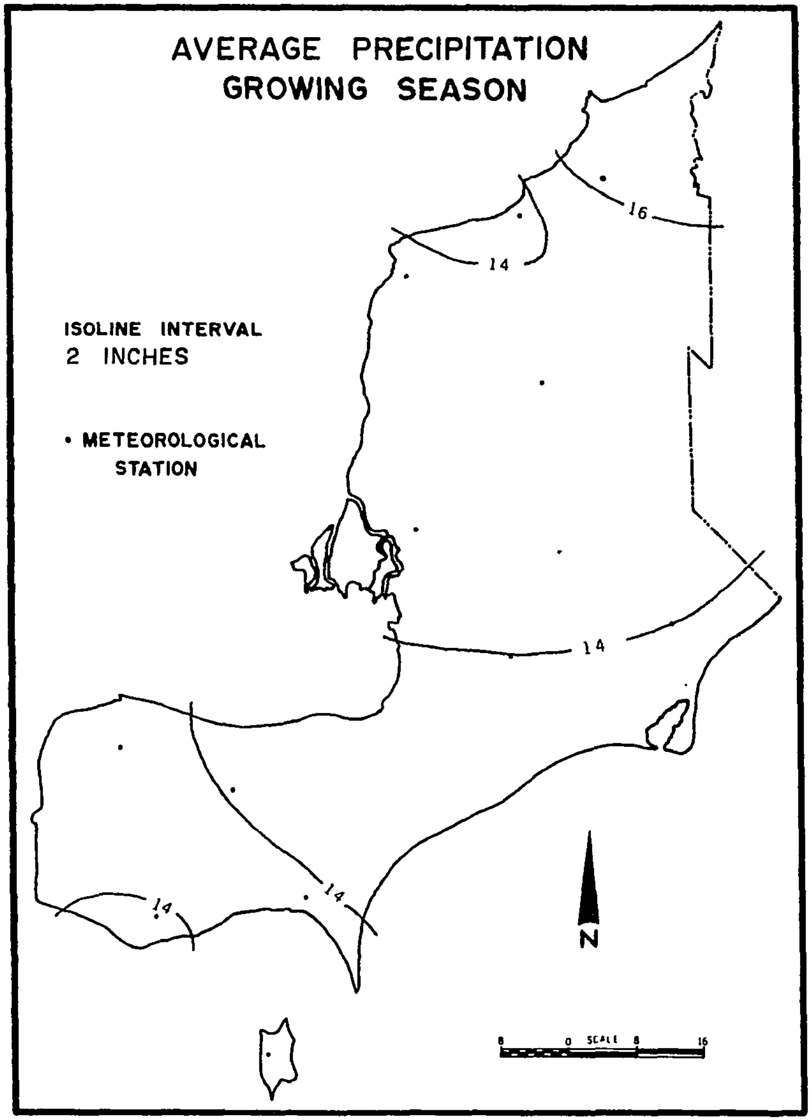


Figure 4

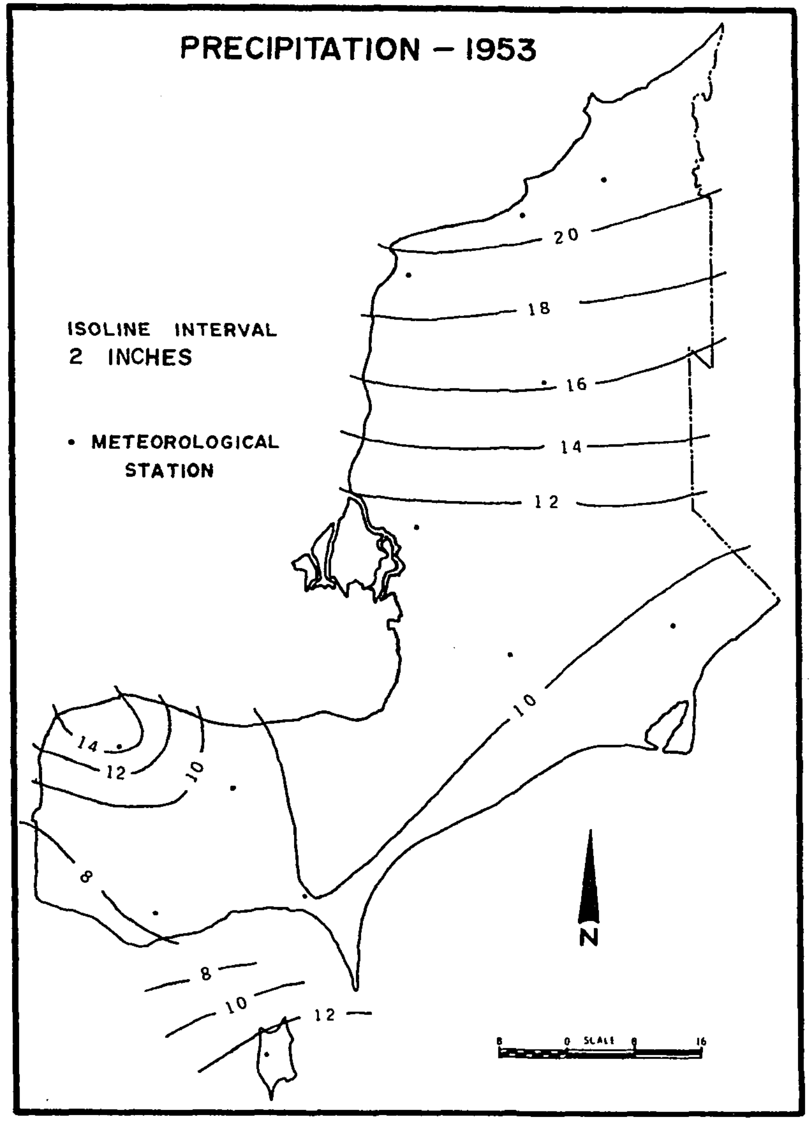


Figure 5

97.5 per cent of all years will have precipitation of less than that shown in Figure 6. This represents the maximum rainfall that can be expected for the area. Essex and Kent counties appear to be the areas of lowest rainfall expected whereas relatively heavy precipitation may occur in the northeast section of Lambton County.

Figure 7 shows the lowest rainfall that can be expected in 97.5 per cent of the years. Relatively uniform conditions exist throughout the region for the minimum precipitation expected, except around Wallaceburg. In one year in 50 the precipitation can be expected to be only 8 inches during the growing season.

The yearly growing season precipitation and potential evapotranspiration at the 12 climatological stations (obtained from the climatic water balance computer programme) is shown in Figure 8. While there is relative stability of potential evapotranspiration, there is a great variability in the amount of moisture received each year with a maximum of 24.7 inches at Forest in 1945 and a minimum of 6.0 inches at Chatham in 1954. This amounts to a variation over the whole region of 18.7 inches of precipitation for the period of study. A great variation can also be found for any one station. Forest had the largest variation with a high of 24.7 inches of precipitation in 1945 and a low of 7.7 inches in 1963 for a difference of 17.0 inches. The highest variation in precipitation in any one year occured in 1953 when a high was recorded at Forest of 21.8 inches and a low at Harrow of 8.7 inches, for a difference of 18.1 inches.

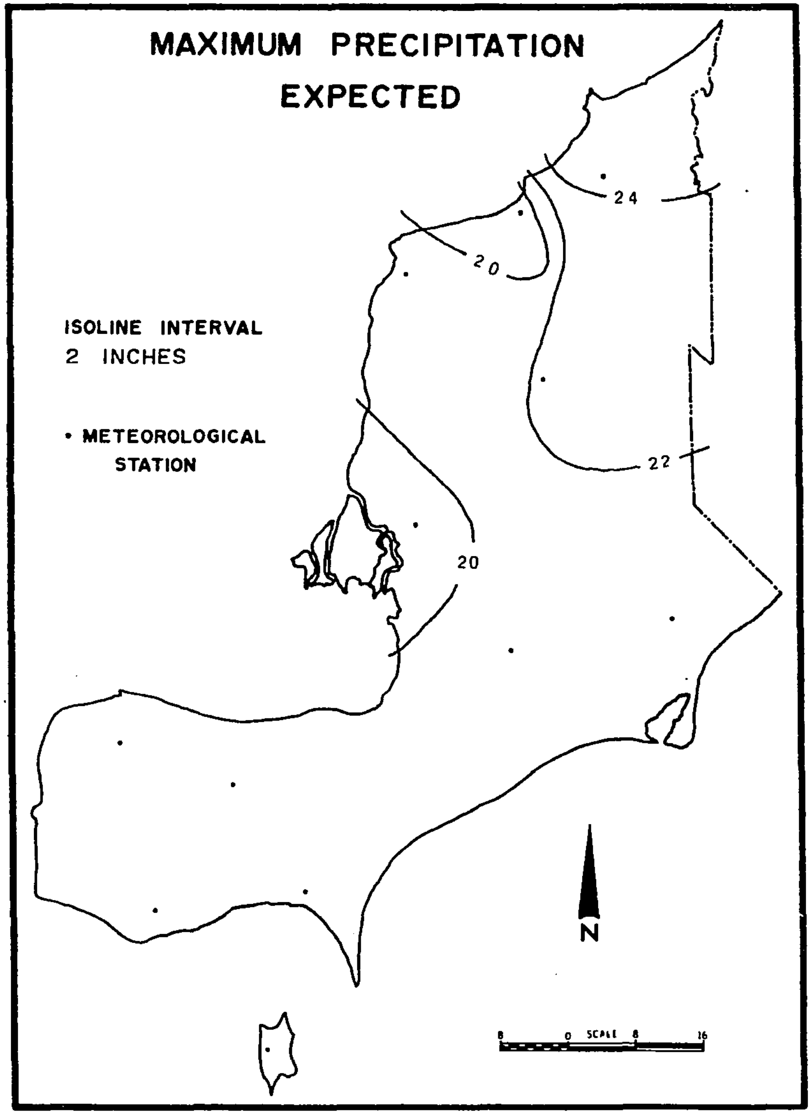


Figure 6

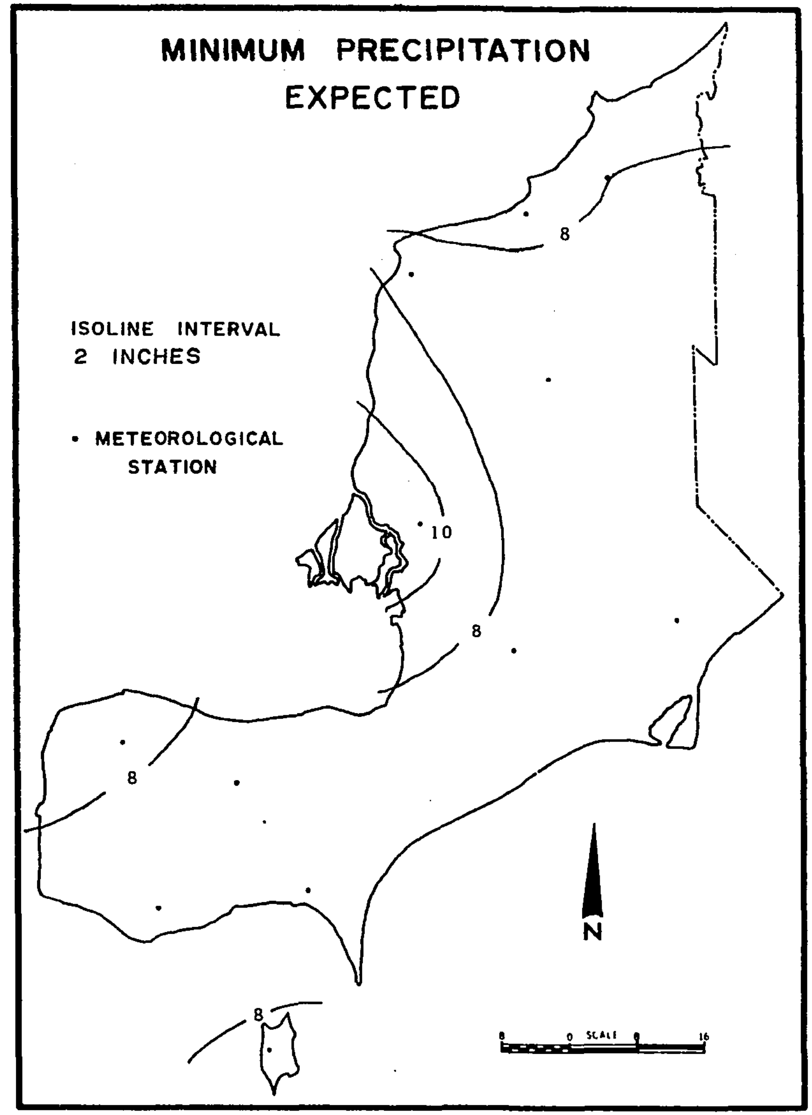


Figure 7

PRECIPITATION AND POTENTIAL EVAPOTRANSPIRATION

GROWING SEASON 1940-1967

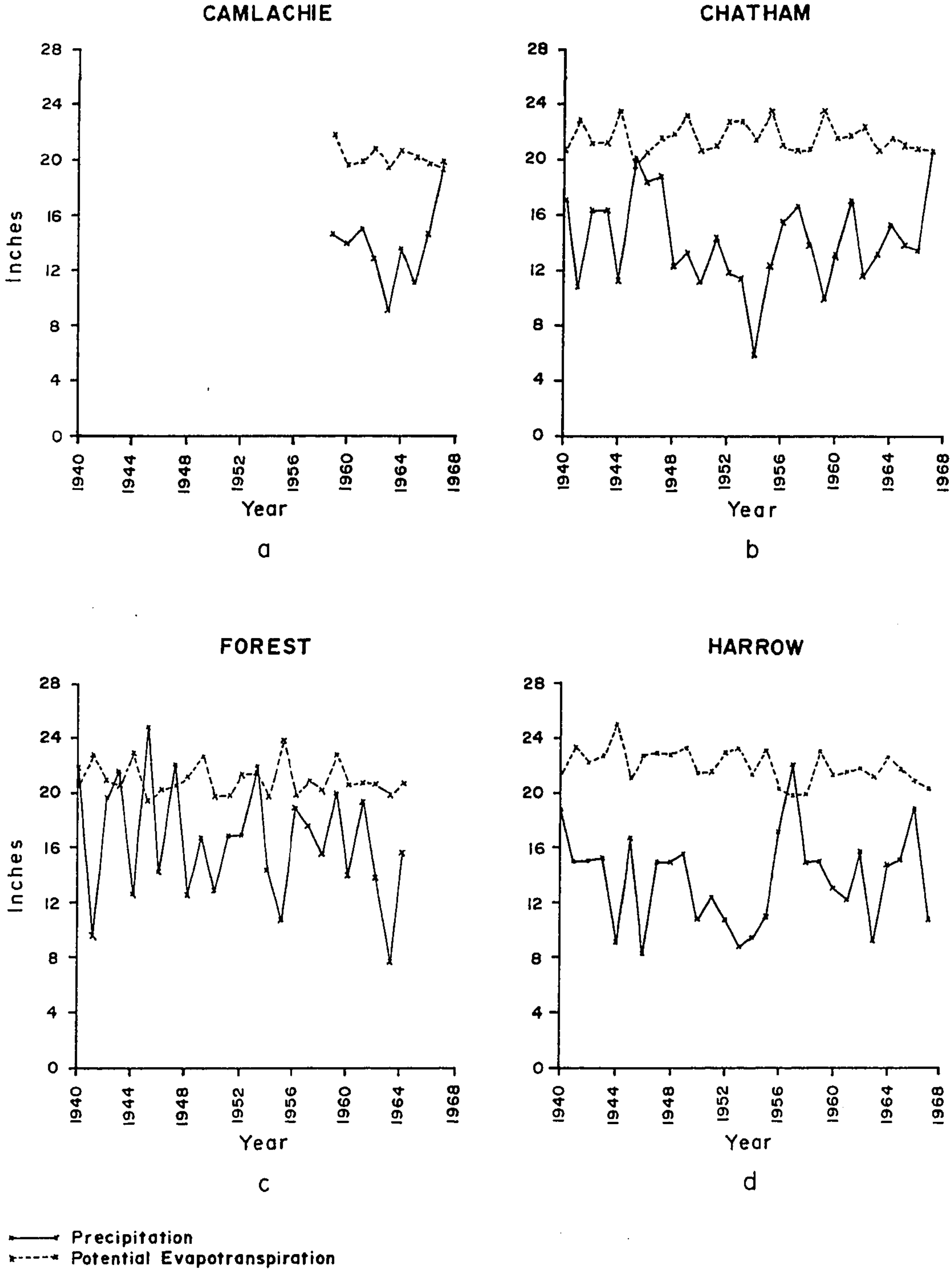


Figure 8

PRECIPITATION AND POTENTIAL EVAPOTRANSPIRATION
GROWING SEASON 1940-1967

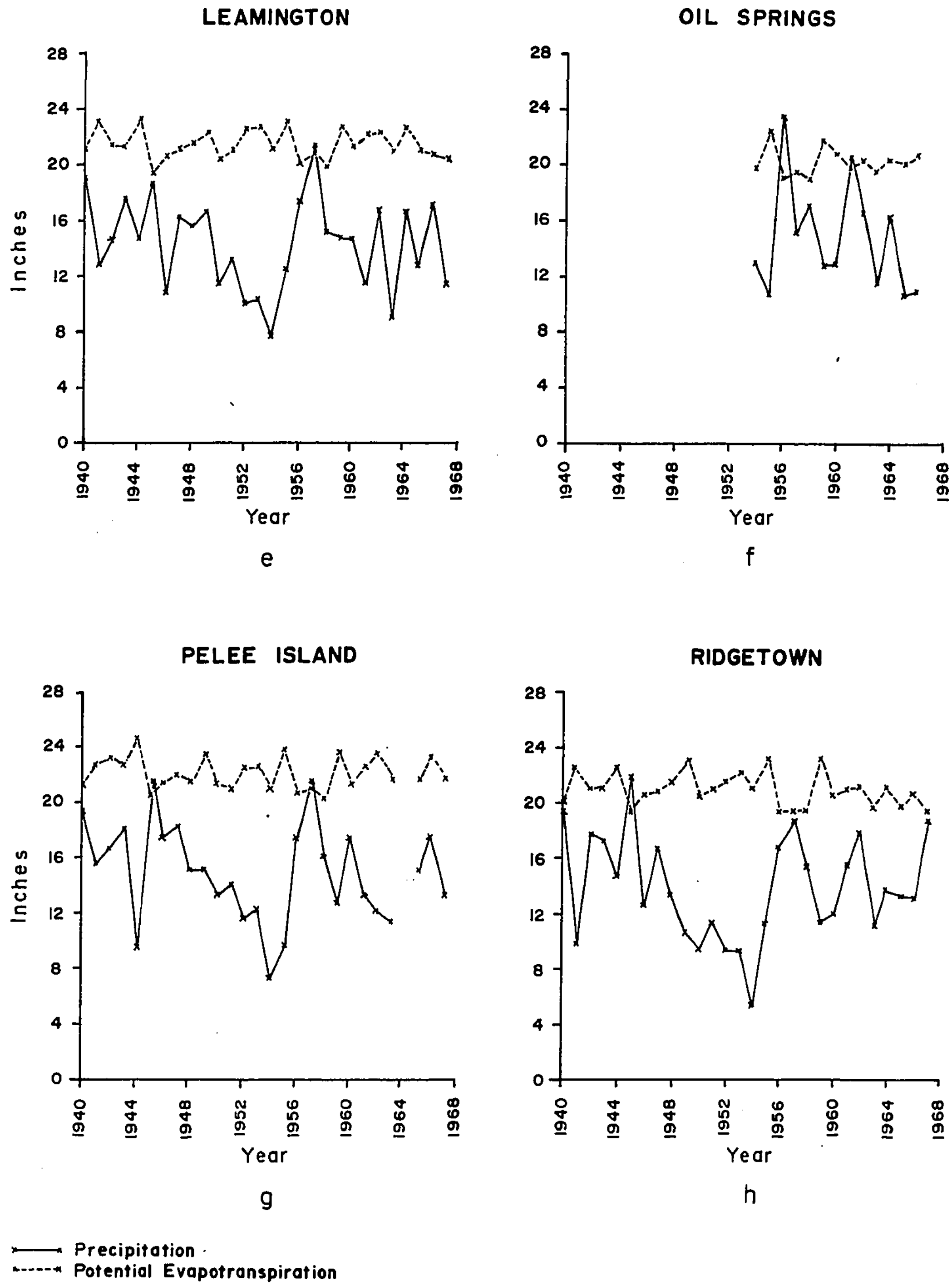


Figure 8--Continued

PRECIPITATION AND POTENTIAL EVAPOTRANSPIRATION

GROWING SEASON 1940-1967

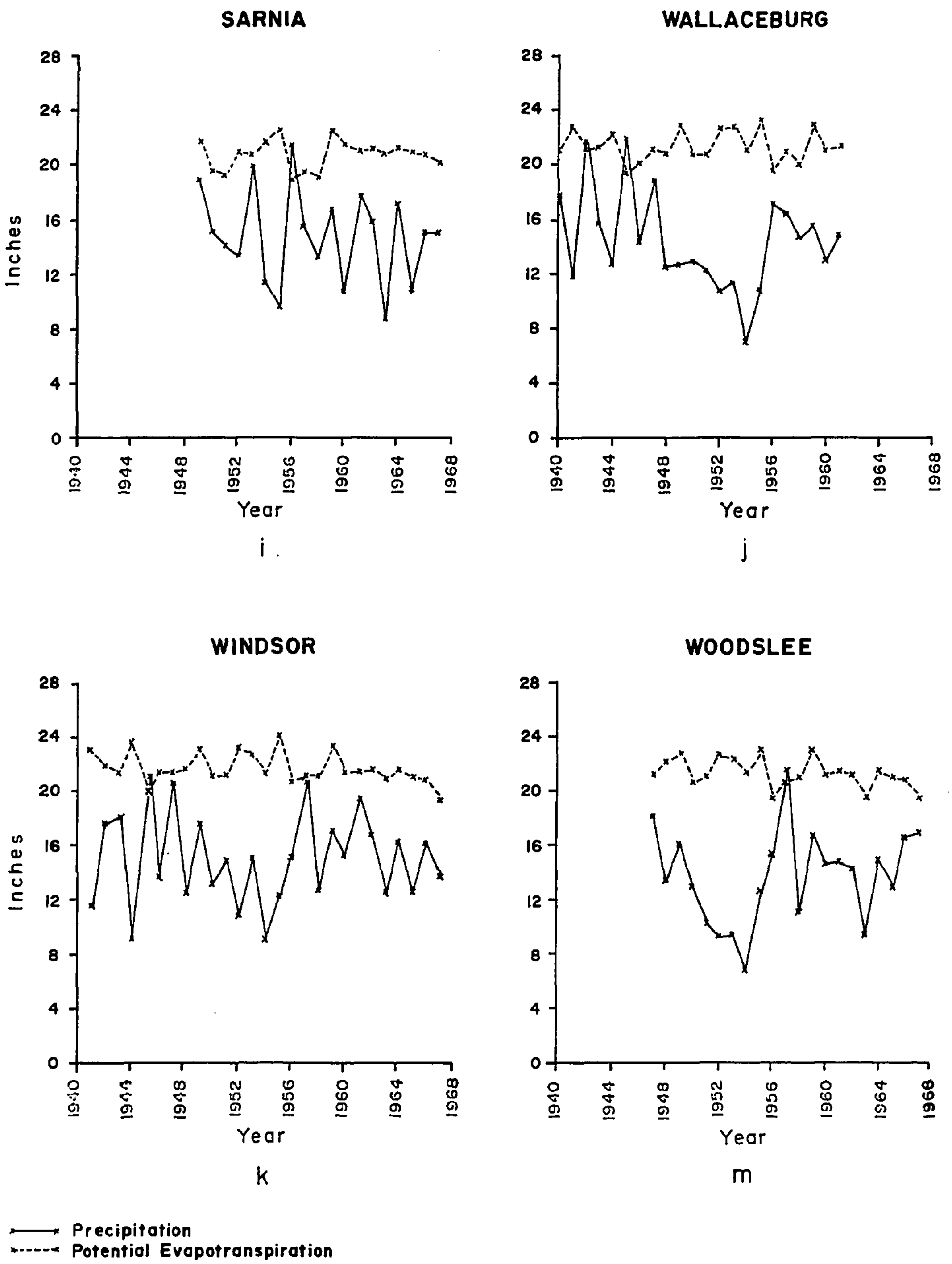


Figure 8--Continued

Potential Evapotranspiration

The potential evapotranspiration, the heat factor in the water balance, appears to be much more uniform. Figure 9 indicates an increase in the average potential evapotranspiration from north to south of only about one inch for the five month growing season. In 1962, the year with the most variation in potential evapotranspiration (Figure 10), the maximum difference was two inches. Figures 11 and 12 showing plus and minus two standard deviations again show a similar pattern, but with larger variations, 4.2 inches for plus two standard deviations and 2.2 inches for minus two standard deviations. In the southern part of Essex County in 1 year in 50 the potential evapotranspiration can be 24 inches, but in 1 year in 50 it can be less than 19 inches.

A maximum of 25.1 inches of potential evapotranspiration occured at Harrow in 1944 and minimum of 19.0 inches at Sarnia and Oil City in 1956 and 1958 respectively for a difference of 6.1 inches of potential evapotranspiration. For one station the greatest variation occured at Harrow where a high of 25.1 inches was recorded in 1944 and a low of 20.0 inches in 1957 and 1958 for a difference of 5.1 inches, a variation of 25 per cent. The year with the greatest variation was 1962 when Pelee Island recorded 23.7 inches of potential evapotranspiration and Forest 20.2 inches for a difference of 3.5 inches.

Deficiency During the Growing Season

To arrive at a quantitative measure of drought intensity and frequency it is necessary to have records of soil moisture deficiency over

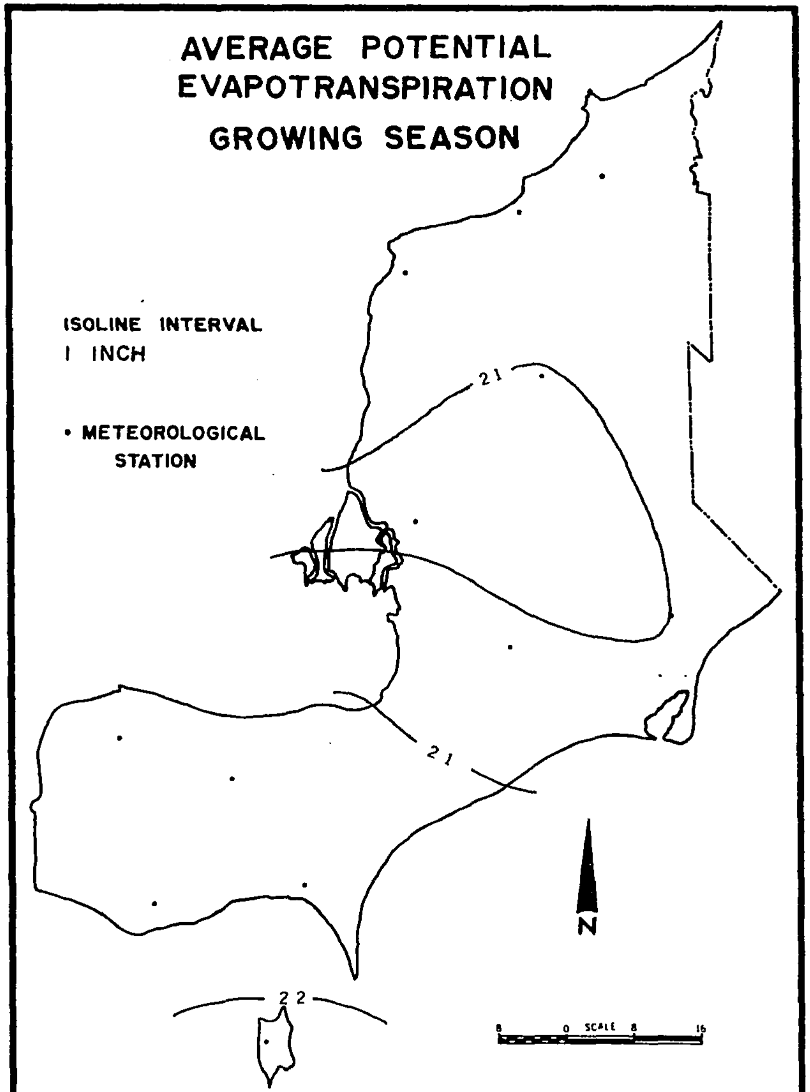


Figure 9

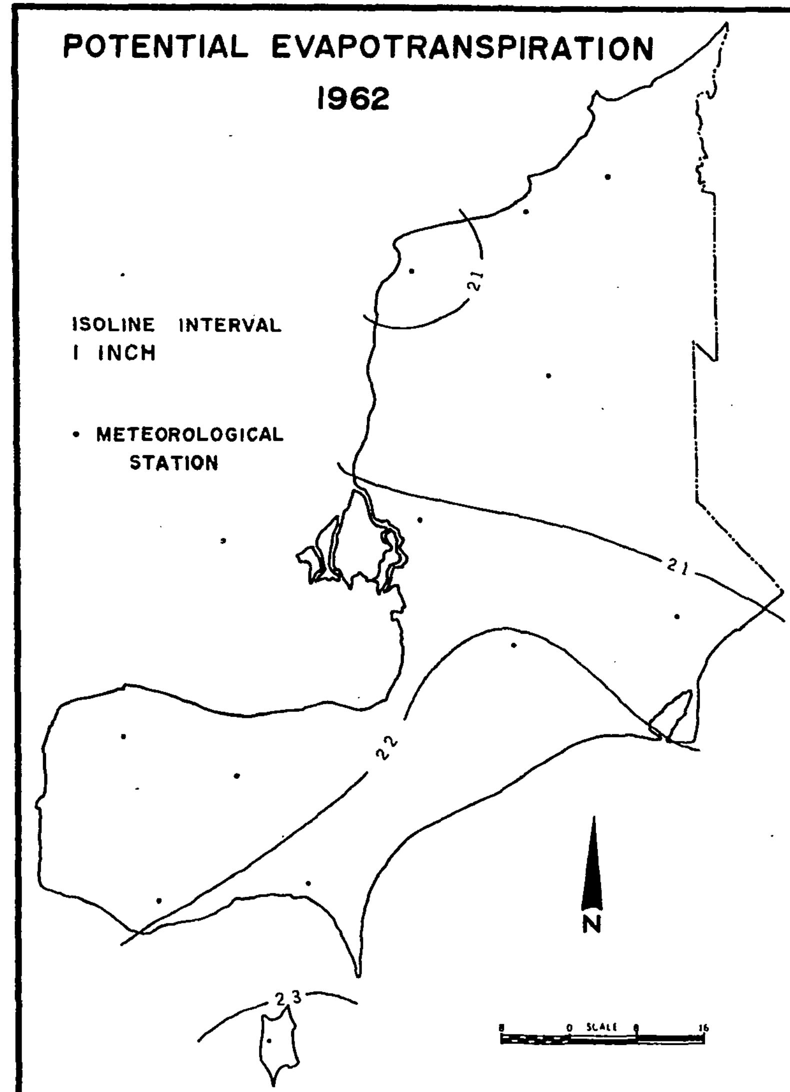


Figure 10

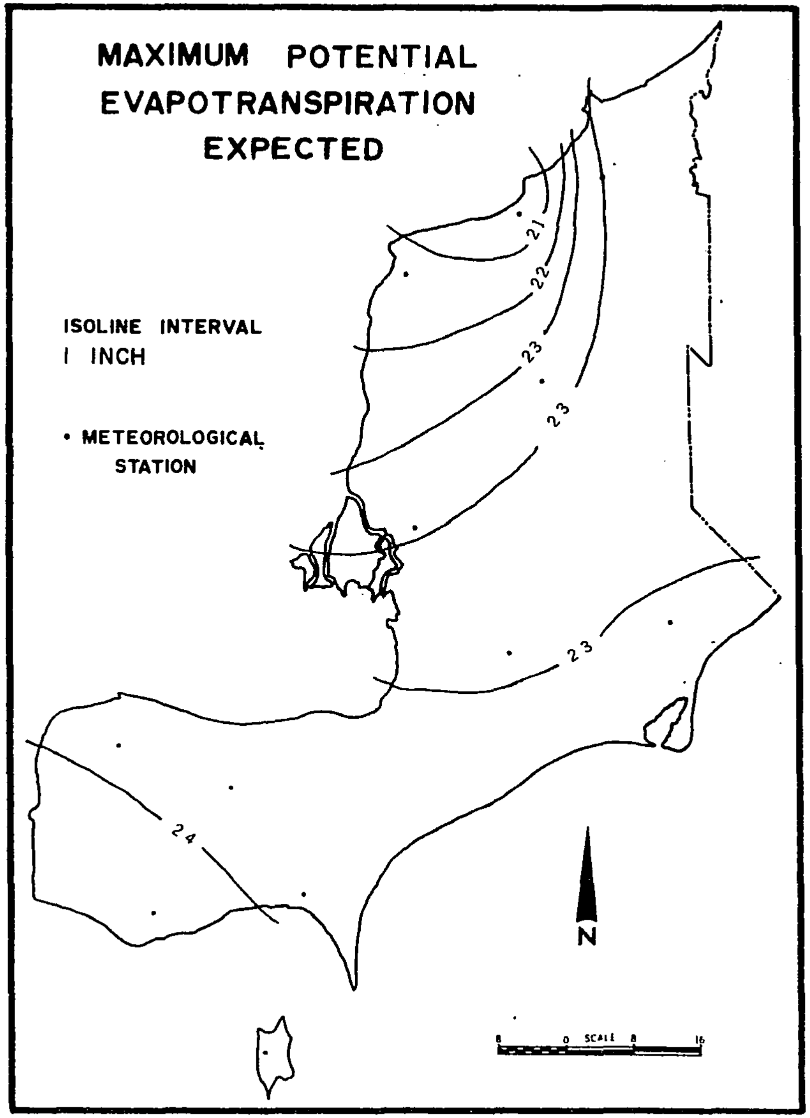


Figure 11

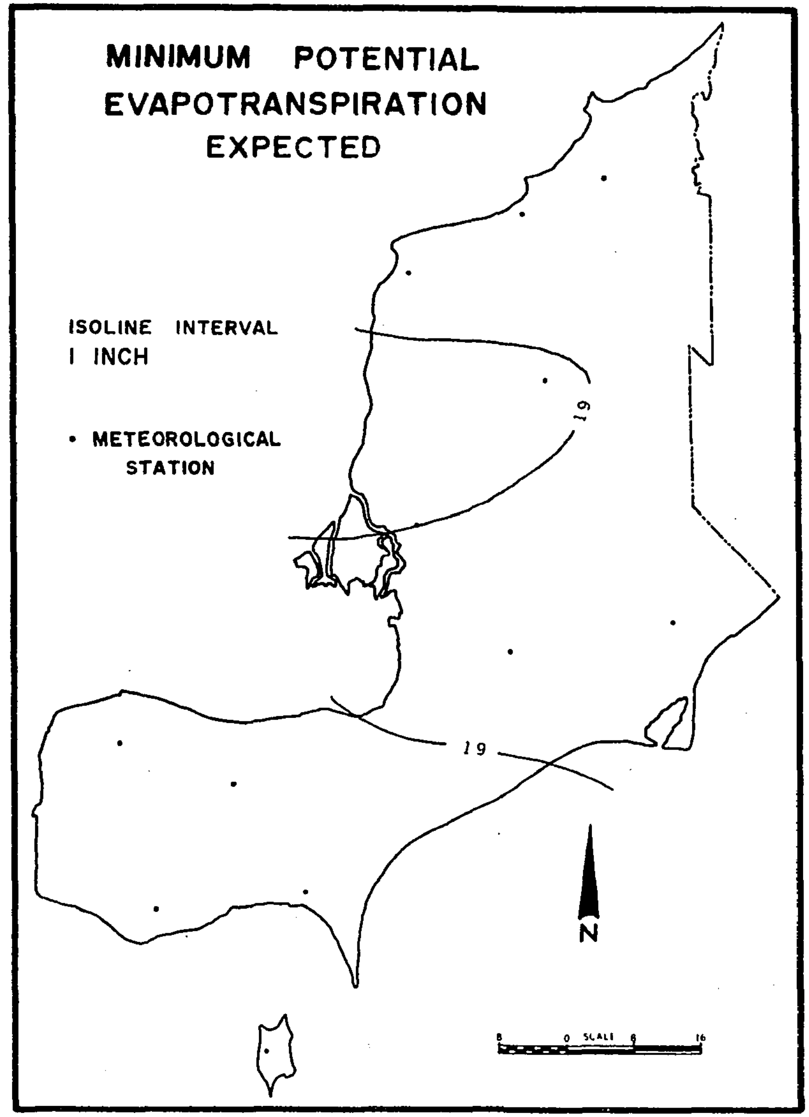


Figure 12

several years. Computerized water balances were run using water holding capacities of 3, 6, and 8 inches for each of the 12 stations within the Region, for the period of time available from 9 to 28 years.

Three stations were selected for purposes of comparison: Harrow, which has the greatest deficiency; Forest, which has the least deficiency; and Ridgetown, which has a deficiency between the two extremes. Figures 13 to 15 show the average monthly precipitation, potential evapotranspiration and monthly deficiency at the three stations using 3, 6, and 8 inch water holding capacities.

All three stations have similar graphs. The potential evapotranspiration is 0 in the winter months but begins to rise in the early spring, reaching a peak in July of between 5.0 and 6.0 inches. It then falls rapidly in autumn until 0 potential evapotranspiration is again reached in December. The precipitation is more evenly distributed throughout the year with a monthly variation at Forest, Ridgetown and Harrow of only 1.0, 1.1, and 1.0 inches respectively.

Although rainfall exceeds potential evapotranspiration on an annual basis at all three stations, during the summer months, the potential evapotranspiration greatly exceeds the precipitation resulting in moisture deficiency at the peak of the growing season. During the late fall and winter when plants do not need water there is a moisture surplus. In the spring and early summer, however, evapotranspiration increases rapidly, soon surpassing the precipitation. At this point the difference between potential evapotranspiration and precipitation is made up by soil moisture storage. But as the soil becomes drier it is unable to make up the difference and moisture deficiency intensifies.

AVERAGE WATER BALANCES AT SELECTED STATIONS

3.0 INCH WATER HOLDING CAPACITY

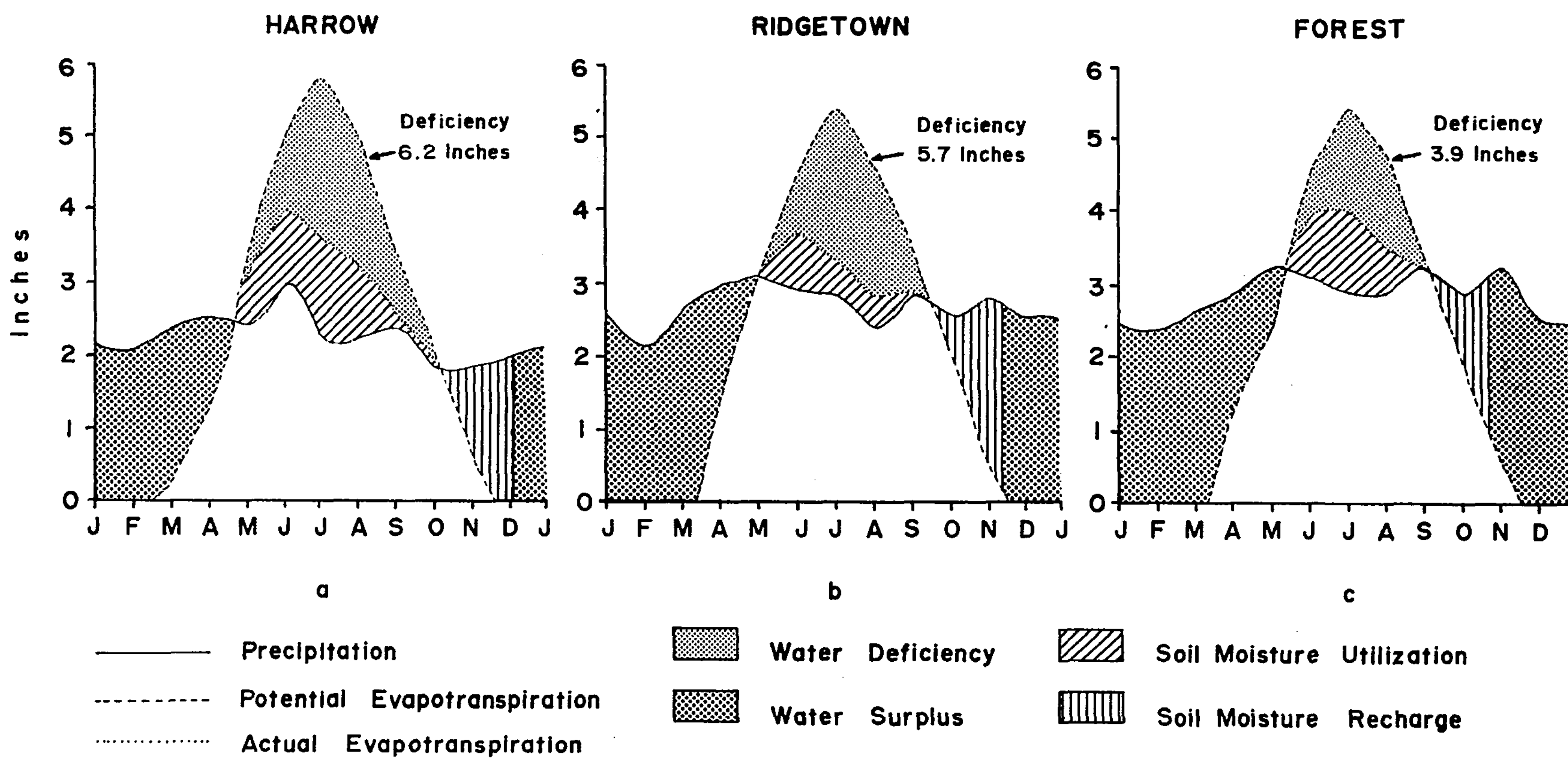


Figure 13

AVERAGE WATER BALANCES AT SELECTED STATIONS
6.0 INCH WATER HOLDING CAPACITY

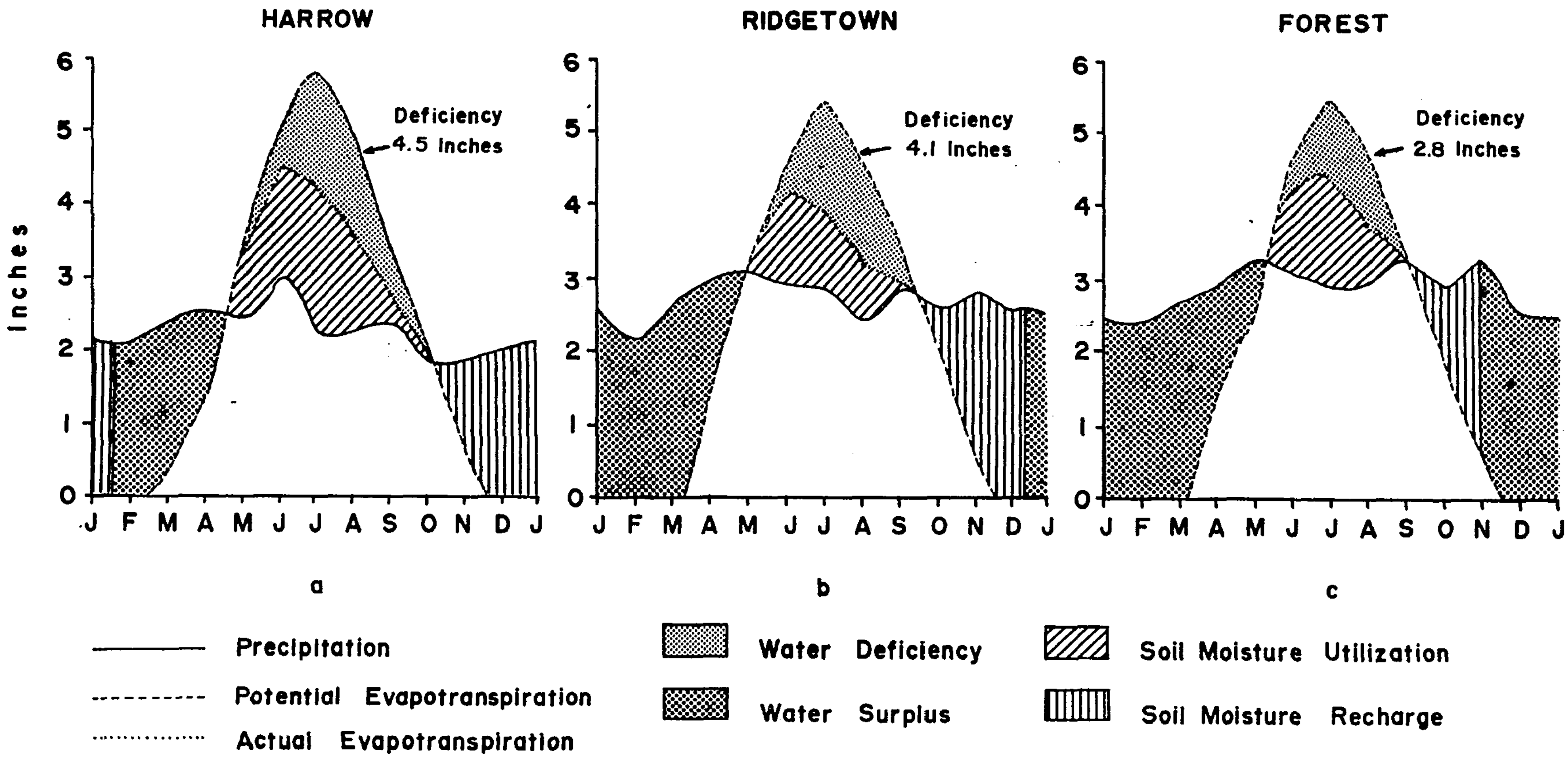


Figure 14

AVERAGE WATER BALANCES AT SELECTED STATIONS
8.0 INCH WATER HOLDING CAPACITY

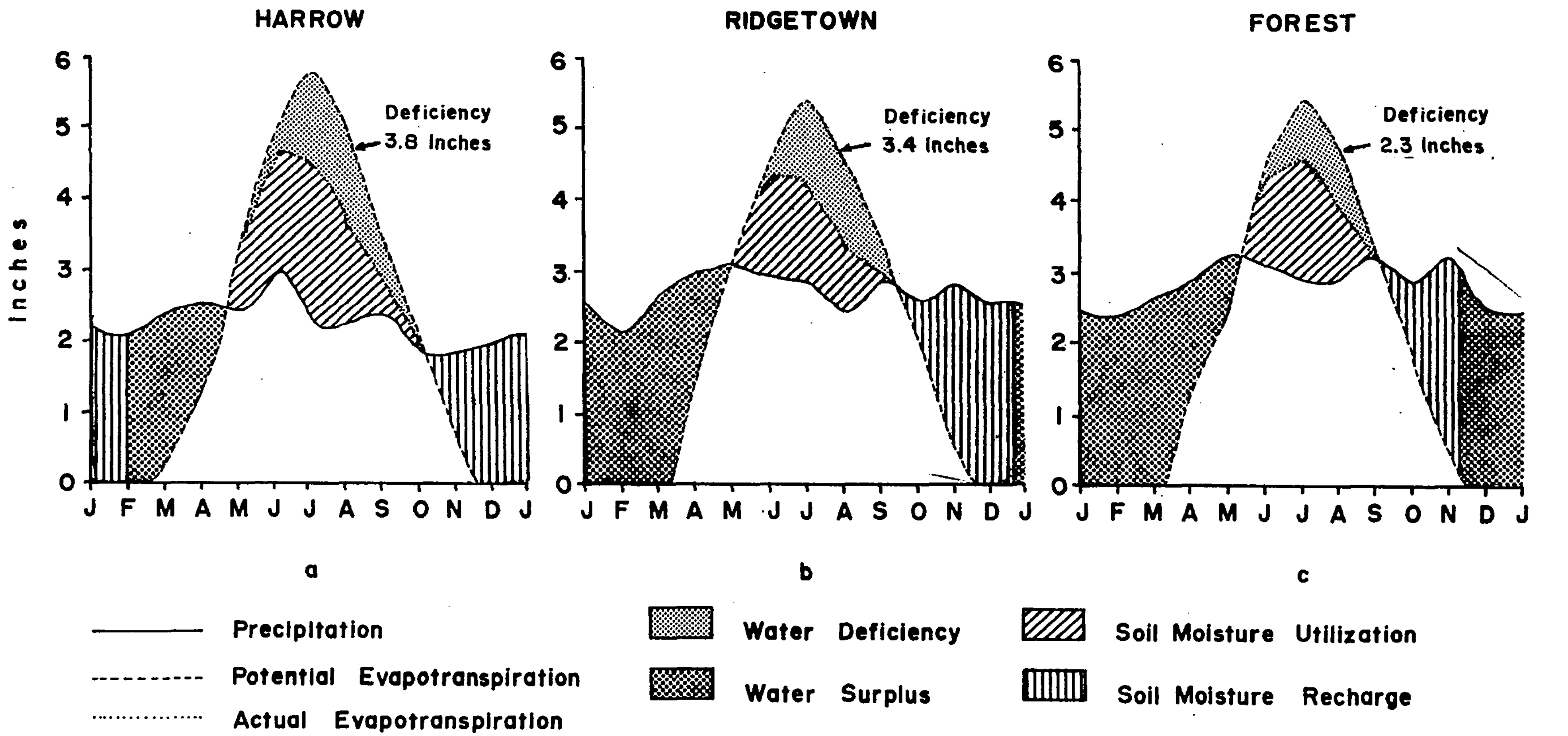


Figure. 15

Figures 13 and 15 show that with a greater water holding capacity, more moisture is available to the plant cover and the soil does not dry as rapidly. This results in the deficiency being greater for soils with a low water holding capacity. This pattern is found when comparing average total water deficiency figures for the growing season. Forest, Ridgetown, and Harrow have average total deficiencies of 3.9, 5.7, and 6.2 for a 3.0 inch water holding capacity, 2.8, 4.1, and 4.5 for a 6.0 inch water holding capacity and 2.3, 3.4, and 3.8 for an 8.0 inch water holding capacity respectively.

The variation of water deficiency at the three stations over the period of study is shown in figure 16. Again the importance of the water holding capacity is emphasized. The greatest variation occured at Harrow where a maximum of 13.1 inches of moisture deficiency occured in 1944 and a minimum of 0.5 in 1957, for a total variation of 12.6 inches for soils with a 3.0 inch water holding capacity. On soils with an 8.0 inch water holding capacity the range of deficiency was from 9.1 inches to 0.2 inches for a difference of 8.9 inches. Ridgetown and Forest follow a similar pattern with a range of 11.6 and 8.2 inches for Ridgetown and a range of 9.8 and 6.5 for Forest for soils with water holding capacity of 3.0 and 8.0 inches respectively.

All three stations show a high possibility of severe drought during the growing season, especially in the sandy soils which have a low water holding capacity (see Table 6). Harrow, for example, has the greatest chance for severe drought with 83.5 per cent of the years having theoretically a deficiency of greater than 3.1 inches on the sandy soils, 2.0 on medium soils and 1.5 on the high moisture retention

VARIATION OF DEFICIENCY

GROWING SEASON 1940-1967

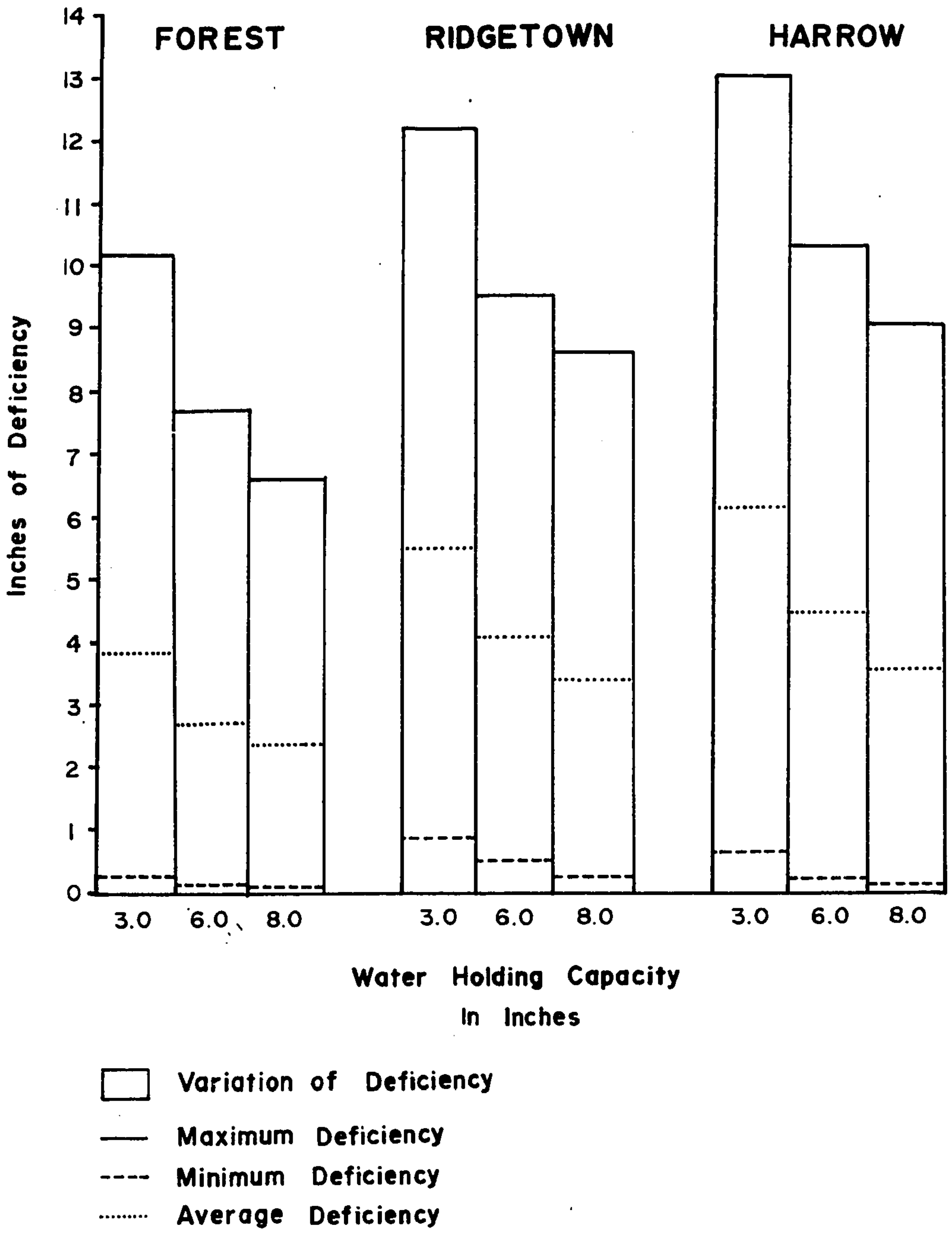


Figure 16

TABLE 6

VARIATIONS IN MOISTURE DEFICIENCY
DURING THE GROWING SEASON

Station	Water Holding Capacity	Mean Moisture Deficiency	Standard Deviation	-1 Standard Deviation*	+1 Standard Deviation **
Camlachie	3.0	4.4	2.0	2.4	6.4
	6.0	3.0	1.5	1.5	4.5
	8.0	2.5	1.3	1.2	3.8
Chatham	3.0	5.9	2.9	3.0	8.8
	6.0	4.2	2.3	1.9	6.5
	8.0	3.6	2.0	1.6	5.6
Forest	3.0	3.9	2.9	1.0	6.8
	6.0	2.8	2.3	.5	5.1
	8.0	2.3	1.9	.4	4.2
Harrow	3.0	6.2	3.1	3.1	9.3
	6.0	4.5	2.6	1.9	7.1
	8.0	3.8	2.3	1.5	6.1
Leamington	3.0	5.5	2.6	2.9	8.1
	6.0	3.9	2.1	1.8	6.0
	8.0	3.3	1.8	1.5	5.1
Oil Springs	3.0	4.4	2.8	1.6	7.2
	6.0	3.1	2.1	1.0	5.6
	8.0	2.6	1.8	.8	4.4
Pelee Island	3.0	5.8	3.0	2.8	8.8
	6.0	4.1	2.4	1.7	6.5
	8.0	3.5	2.1	1.4	5.6
Ridgetown	3.0	5.7	3.1	2.6	8.8
	6.0	4.1	2.5	1.6	6.6
	8.0	3.4	2.2	1.2	5.6

TABLE 6--Continued

Station	Water Holding Capacity	Mean Moisture Deficiency	Standard Deviation	-1 Standard Deviation*	+1 Standard Deviation**
Sarnia	3.0	4.3	2.6	1.7	6.9
	6.0	2.9	2.0	.9	4.9
	8.0	2.4	1.7	.7	4.1
Wallaceburg	3.0	5.6	2.6	3.0	8.2
	6.0	4.2	2.1	2.1	6.3
	8.0	3.5	1.8	1.7	5.3
Windsor	3.0	5.2	2.6	2.6	7.8
	6.0	3.7	2.1	1.6	5.8
	8.0	3.1	1.8	1.3	4.9
Woodslee	3.0	5.6	2.8	2.8	8.4
	6.0	4.0	2.3	1.7	6.3
	8.0	3.3	2.0	1.3	5.3

* 83.5 per cent of all cases are greater than -1 Standard Deviation.

** 83.5 per cent of all cases are less than +1 Standard Deviation.

soils. The degree of deficiency becomes less in the more humid areas of the region but the danger of invisible drought is still present.

Monthly Deficiency

Crops vary as to the time when a water deficiency will be most harmful or when they can best resist a deficiency. A deficiency of moisture during the early stages of growth for corn will delay silking, tasseling, and maturity. If by tasseling[5] time the water deficit is overcome and moisture is available for the remainder of the growing season the crop yield will not be seriously damaged.[6]

A moisture deficiency during silking and tasseling will greatly decrease the yields of corn. Experiments in Washington found that a depletion of available moisture during silking and tasseling decreased yields by 22 to 50 per cent.[7] Following this period a moisture deficiency will not greatly decrease crop production. A moisture deficiency during the entire growing season will result in stunted plants, slow maturity and poor yield. An experiment in Nebraska, found that with a moisture deficiency throughout the growing season a yield of 69 bushels per acre of corn resulted, whereas under conditions of adequate moisture the yields increased to 153 bushels.[8]

In the St. Clair Region there is a moisture deficiency throughout the growing season, with the greatest deficiency occuring during the hot summer months when corn and other crops are at a critical stage of growth when they need sufficient moisture to mature properly. Figures 17 to 22 show the average deficiency over the growing season as well as the average deficiency for each of the five months. The maps

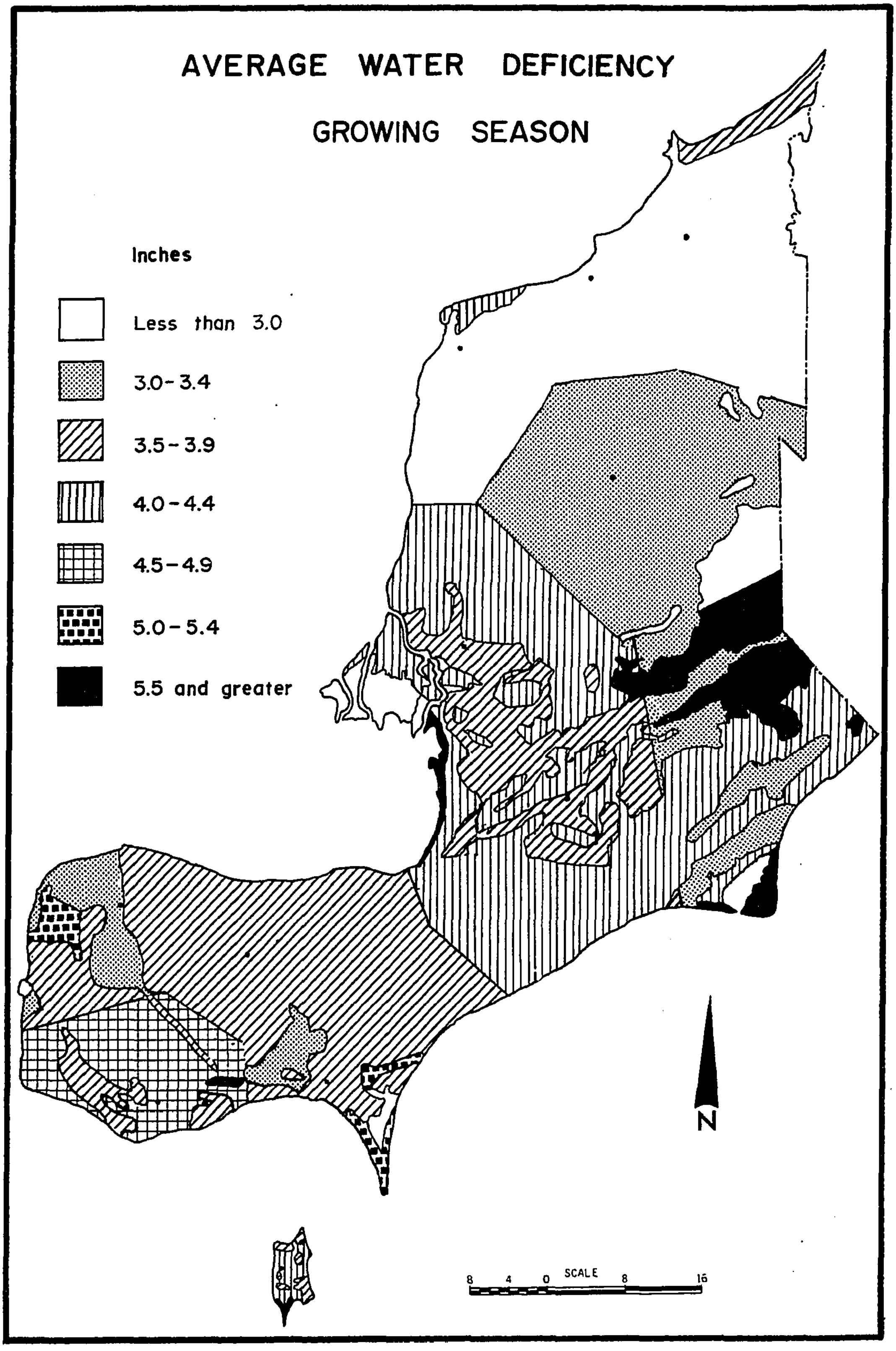

AVERAGE WATER DEFICIENCY
GROWING SEASON
Inches
Less than 3.0
3.0-3.4
3.5-3.9
4.0-4.4
4.5-4.9
5.0-5.4
5.5 and greater
N
SCALE
8 4 0 8 16

Figure 17

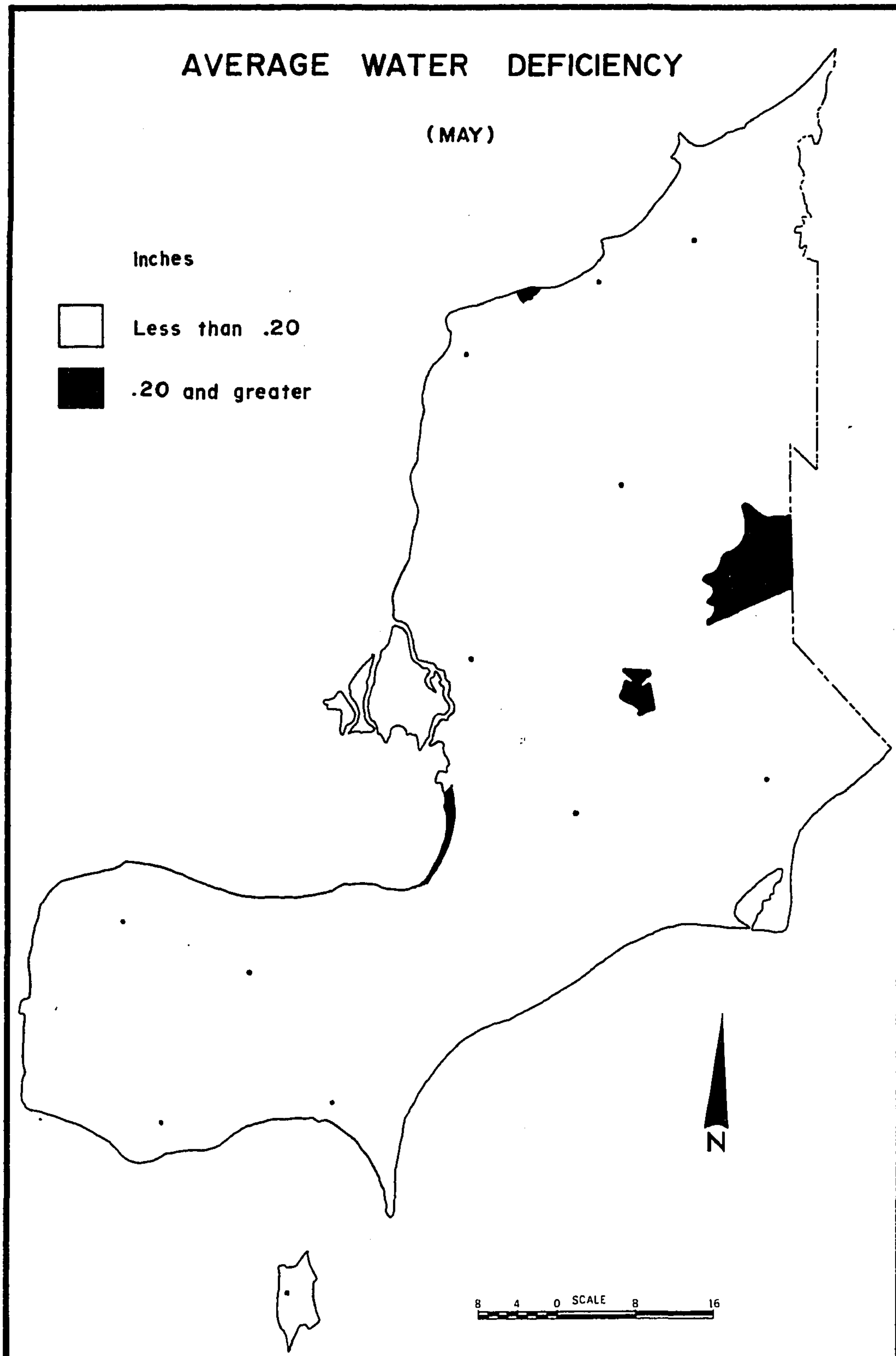

AVERAGE WATER DEFICIENCY
(MAY)
Inches
Less than .20
.20 and greater
N
8 4 0 SCALE 8 16

Figure 18

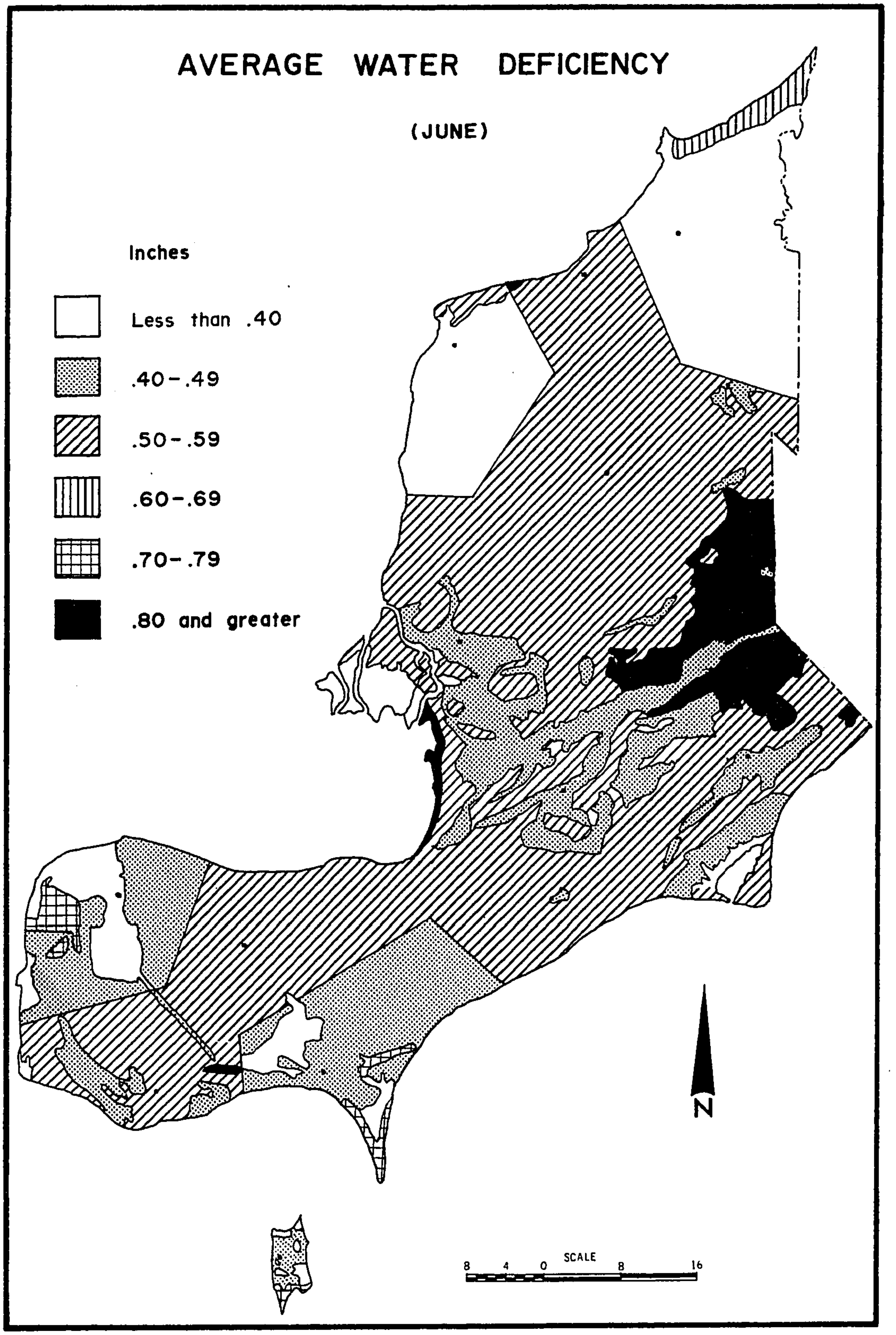

AVERAGE WATER DEFICIENCY
(JUNE)
Inches
Less than .40
.40-.49
.50-.59
.60-.69
.70-.79
.80 and greater
N
SCALE
8 4 0 8 16

Figure 19

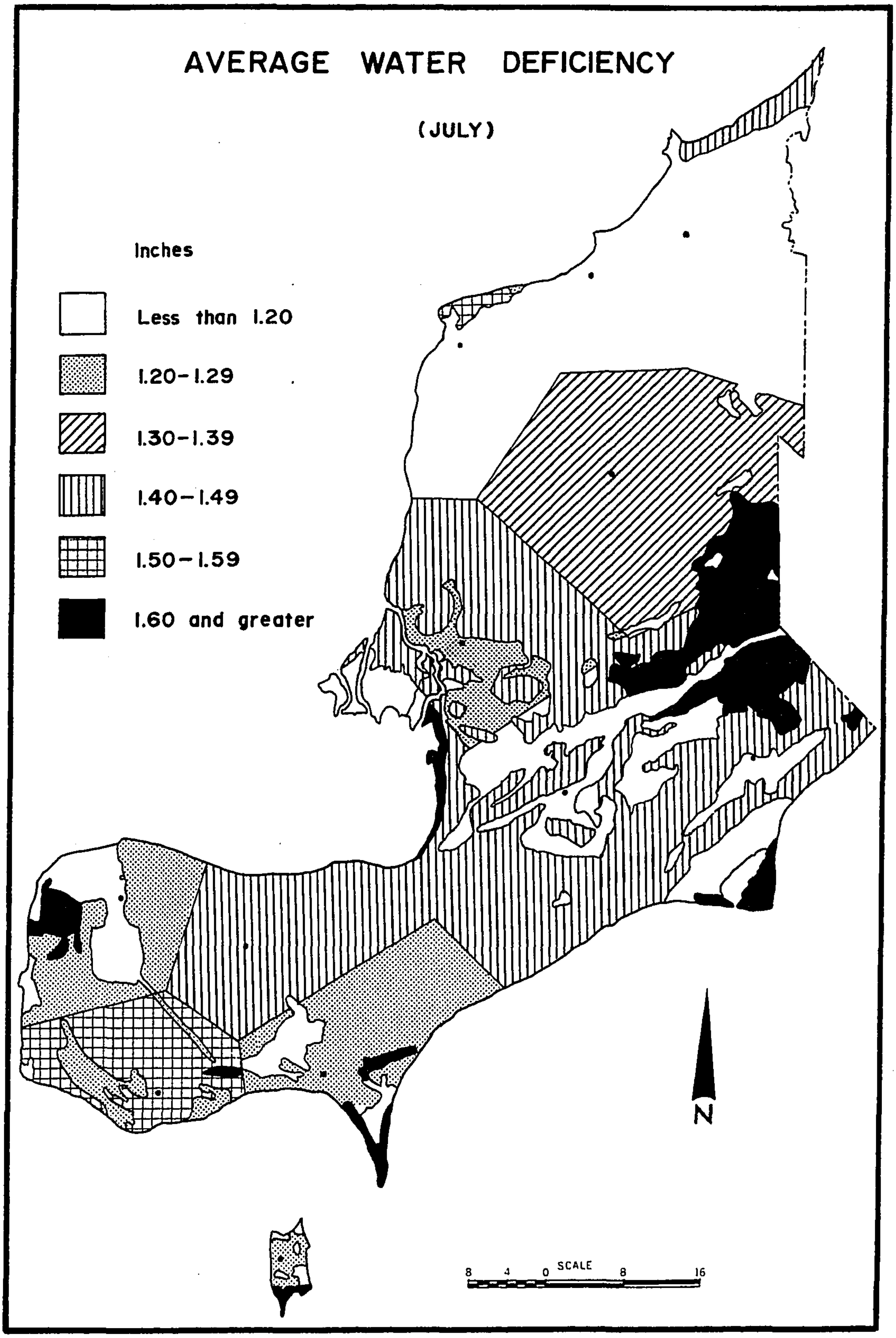

AVERAGE WATER DEFICIENCY
(JULY)
Inches
Less than 1.20
1.20-1.29
1.30-1.39
1.40-1.49
1.50-1.59
1.60 and greater
N
SCALE
8 4 0 8 16

Figure 20

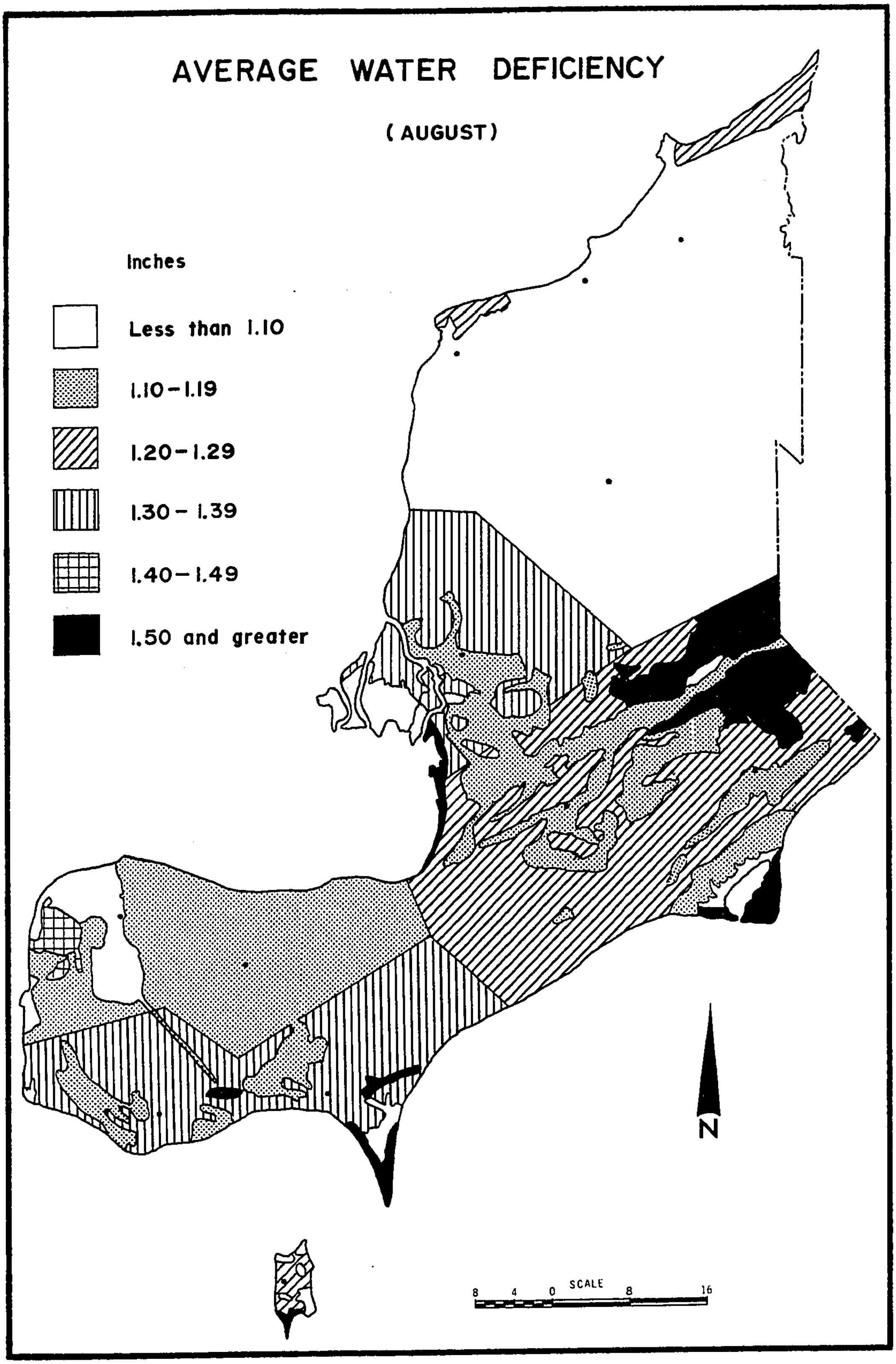

AVERAGE WATER DEFICIENCY
(AUGUST)
Inches
Less than 1.10
1.10-1.19
1.20-1.29
1.30 - 1.39
1.40-1.49
1.50 and greater
N
SCALE
8 4 0 8 16

Figure 21

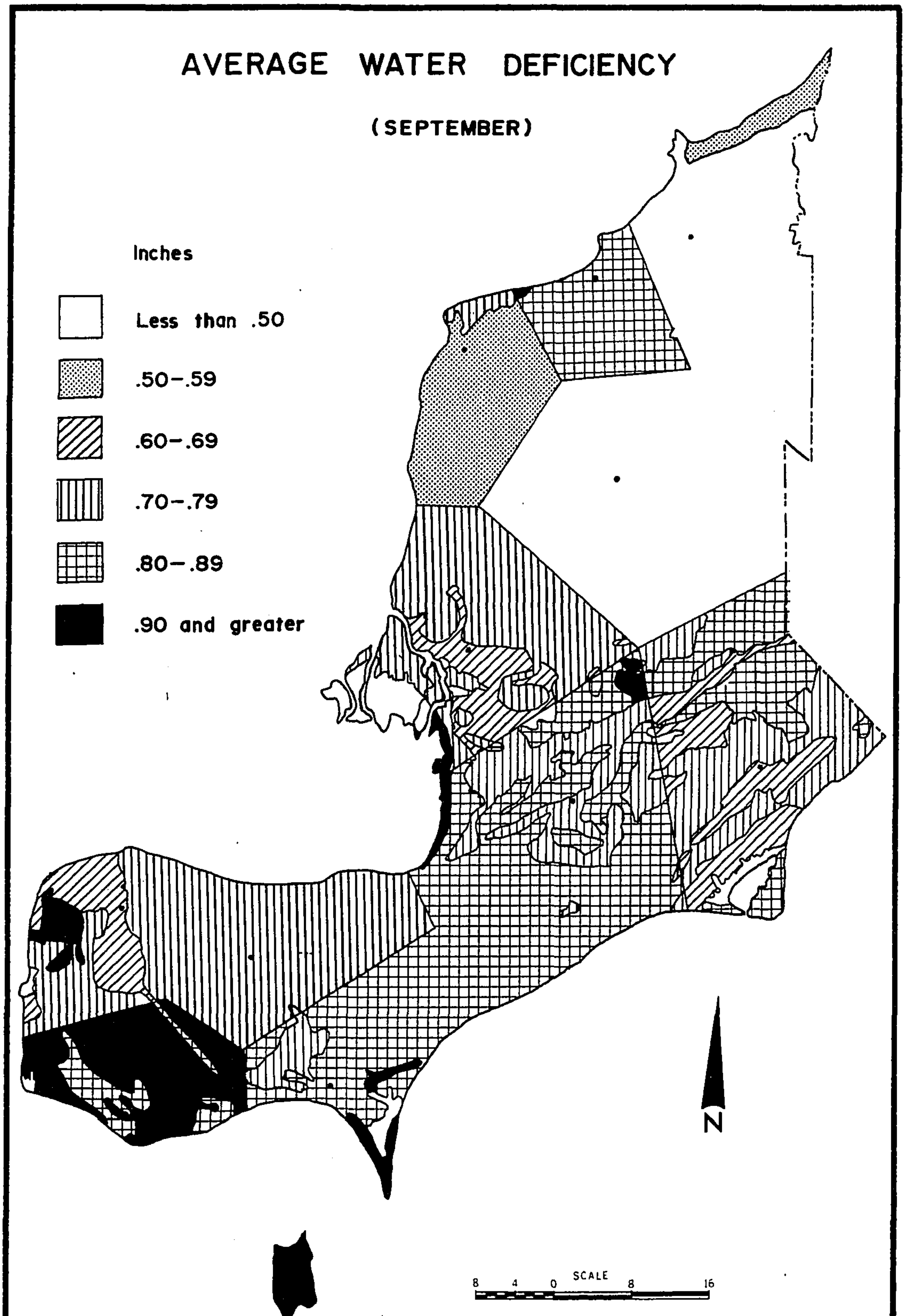

AVERAGE WATER DEFICIENCY
(SEPTEMBER)
Inches
Less than .50
.50-.59
.60-.69
.70-.79
.80-.89
.90 and greater
N
SCALE
8 4 0 8 16

Figure 22

were constructed by using the Theissen polygon method to determine the area of influence for each of the 12 climatological stations. Within these areas moisture deficiencies were found for the various soils by use of the water balance computer programme.

Figures 17 to 22 show a general trend of increasing moisture deficiency from north to south. In Figure 17 the 6 inch water holding capacity soils have a deficiency of less than 3.0 inches in areas influenced by the three most northerly climatological stations, whereas in Essex County the soils with a 6 inch water holding capacity have deficiencies ranging from 3.5 to 4.9 inches. Figures 18 to 22 show that the highest moisture deficiencies occur on sandy soils throughout the region in all summer months, the least deficiencies on the silt and clay loams especially around Windsor and in northern Lambton County.

The expected frequencies and severity of water deficiency by month for the 12 stations in the St. Clair Region are summarized in Table 7. The most critical shortage of water occurs in the months of July and August with a maximum average deficit at Harrow on sandy soils of 2.2 inches in July and the least for the two months at Forest with an average deficit of 0.8 inches in both July and August. Even in the area of least deficiency around Forest only 18 per cent of the years recorded had no deficit in either July or August on soils of 8.0 inches water holding capacity and only 2 per cent of the years recorded no deficit in both months. To the other extreme Harrow recorded only 12.5 per cent of the years with no deficit in either July and August and none of the years recorded no deficit for both July and August.

TABLE 7

VARIATIONS IN MOISTURE DEFICIENCY
BY MONTH

May

Station	Water Holding Capacity	Mean Moisture Deficiency	Standard Deviation	-1 Standard Deviation*	+1 Standard Deviation**
Camlachie	3.0	.2	.3	0	.5
	6.0	.1	.2	0	.3
	3.0	.1	.1	0	.2
Chatham	3.0	.2	.3	0	.5
	6.0	.1	.2	0	.3
	8.0	.1	.1	0	.2
Forest	3.0	.1	.2	0	.3
	6.0	.1	.1	0	.2
	8.0	.1	.1	0	.2
Harrow	3.0	.2	.3	0	.5
	6.0	.1	.2	0	.3
	8.0	.1	.1	0	.2
Leamington	3.0	.1	.2	0	.3
	6.0	.1	.1	0	.2
	8.0	.1	.1	0	.2
Oil Springs	3.0	.2	.3	0	.5
	6.0	.1	.2	0	.3
	8.0	.1	.1	0	.2
Pelee Island	3.0	.1	.3	0	.4
	6.0	.1	.1	0	.2
	8.0	.1	.1	0	.2
Ridgetown	3.0	.2	.3	0	.5
	6.0	.1	.2	0	.3
	8.0	.1	.1	0	.2
Sarnia	3.0	.2	.3	0	.5
	6.0	.1	.2	0	.3
	8.0	.1	.1	0	.2

TABLE 7--Continued

May

Station	Water Holding Capacity	Mean Moisture Deficiency	Standard Deviation	-1 Standard Deviation*	+1 Standard Deviation**
Wallaceburg	3.0	.2	.3	0	.5
	6.0	.1	.1	0	.2
	8.0	.1	.1	0	.2
Windsor	3.0	.2	.3	0	.5
	6.0	.1	.1	0	.2
	8.0	.1	.1	0	.2
Woodslee	3.0	.2	.3	0	.5
	6.0	.1	.2	0	.3
	8.0	.1	.1	0	.2

June

Station	Water Holding Capacity	Mean Moisture Deficiency	Standard Deviation	-1 Standard Deviation*	+1 Standard Deviation**
Camlachie	3.0	.8	.9	0	1.7
	6.0	.5	.6	0	1.1
	8.0	.4	.5	0	.9
Chathan	3.0	1.0	.8	.2	1.8
	6.0	.6	.5	.1	1.1
	8.0	.5	.4	.1	.9
Forest	3.0	.6	.7	0	1.3
	6.0	.4	.4	0	.8
	8.0	.3	.3	0	.6
Harrow	3.0	1.0	.8	.2	1.8
	6.0	.6	.5	.1	1.1
	8.0	.5	.4	.1	.9
Leamington	3.0	.7	.6	.1	1.3
	6.0	.4	.4	0	.8
	8.0	.3	.3	0	.6
Oil Springs	3.0	.8	.9	0	1.7
	6.0	.5	.6	0	1.1
	8.0	.4	.5	0	.9

TABLE 7--Continued

June

Station	Water Holding Capacity	Mean Moisture Deficiency	Standard Deviation	-1 Standard Deviation*	+1 Standard Deviation**
Pelee Island	3.0	.8	.7	.1	1.5
	6.0	.5	.5	0	1.0
	8.0	.4	.4	0	.8
Ridgetown	3.0	.8	.8	0	1.6
	6.0	.5	.5	0	1.0
	8.0	.4	.4	0	.8
Sarnia	3.0	.6	.6	0	1.2
	6.0	.3	.4	0	.7
	8.0	.3	.3	0	.6
Wallaceburg	3.0	.8	.8	0	1.6
	6.0	.5	.5	0	1.0
	8.0	.4	.4	0	.8
Windsor	3.0	.8	.8	0	1.6
	6.0	.5	.5	0	1.0
	8.0	.4	.4	0	.8
Woodslee	3.0	.9	.7	.2	1.6
	6.0	.6	.4	.2	1.0
	8.0	.5	.4	.1	.9
		July			
Camlachie	3.0	1.2	.7	.5	1.9
	6.0	.8	.5	.3	1.3
	8.0	.7	.4	.3	1.1
Chatham	3.0	2.0	1.1	.9	3.1
	6.0	1.4	.9	.5	2.3
	8.0	1.2	.7	.5	1.9
Forest	3.0	1.4	1.3	.1	2.7
	6.0	1.0	.9	.1	1.9
	8.0	.8	.8	0	1.6
Harrow	3.0	2.2	1.3	.9	3.5
	6.0	1.5	1.0	.5	2.5
	8.0	1.2	.8	.4	2.0

TABLE 7--Continued

July

Station	Water Holding Capacity	Mean Moisture Deficiency	Standard Deviation	-1 Standard Deviation*	+1 Standard Deviation**
Leamington	3.0	1.9	1.1	.8	3.0
	6.0	1.3	.8	.5	2.1
	8.0	1.0	.7	.3	1.7
Oil Springs	3.0	1.9	1.2	.7	3.1
	6.0	1.3	.9	.4	2.2
	8.0	1.1	.8	.3	1.9
Pelee Island	3.0	1.8	1.2	.6	3.0
	6.0	1.3	.9	.4	2.2
	8.0	1.0	.8	.2	1.8
Ridgetown	3.0	2.1	1.1	1.0	3.2
	6.0	1.4	.9	.5	2.3
	8.0	1.2	.8	.4	2.0
Sarnia	3.0	1.5	1.2	.3	2.7
	6.0	1.0	.8	.2	1.8
	8.0	.8	.7	.1	1.5
Wallaceburg	3.0	2.1	1.1	1.0	3.2
	6.0	1.4	.9	.5	2.3
	8.0	1.2	.8	.4	2.0
Windsor	3.0	1.9	.9	1.0	2.8
	6.0	1.3	.7	.6	2.0
	8.0	1.0	.6	.4	1.6
Woodslee	3.0	2.1	1.1	1.0	3.2
	6.0	1.4	.8	.6	2.2
	8.0	1.2	.7	.5	1.9

August

Station	Water Holding Capacity	Mean Moisture Deficiency	Standard Deviation	-1 Standard Deviation*	+1 Standard Deviation**
Camlachie	3.0	1.1	.9	.2	2.0
	6.0	.8	.7	.1	1.5
	3.0	.6	.6	0	1.2

TABLE 7--Continued

August

Station	Water Holding Capacity	Mean Moisture Deficiency	Standard Deviation	-1 Standard Deviation*	+1 Standard Deviation**
Chatham	3.0	1.7	1.3	.4	3.0
	6.0	1.3	1.0	.3	2.3
	8.0	1.1	.9	.2	2.0
Forest	3.0	1.3	1.1	.2	2.4
	6.0	.9	.8	.1	1.7
	8.0	.8	.7	.1	1.5
Harrow	3.0	1.7	1.2	.5	2.9
	6.0	1.3	1.0	.3	2.3
	8.0	1.2	.9	.3	2.1
Leamington	3.0	1.8	1.2	.6	3.0
	6.0	1.3	1.0	.3	2.3
	8.0	1.1	.8	.3	1.9
Oil Springs	3.0	1.1	1.1	0	2.2
	6.0	.8	.8	0	1.6
	8.0	.7	.7	0	1.4
Pelee Island	3.0	1.6	1.2	.4	2.8
	6.0	1.3	1.0	.3	2.3
	8.0	1.1	.8	.3	1.9
Ridgetown	3.0	1.7	1.2	.5	2.9
	6.0	1.3	1.0	.3	2.3
	8.0	1.1	.8	.3	1.9
Sarnia	3.0	1.2	.9	.3	2.1
	6.0	.9	.7	.2	1.6
	8.0	.8	.6	.1	1.4
Wallaceburg	3.0	1.8	1.1	.7	2.9
	6.0	1.4	.9	.5	2.3
	8.0	1.2	.8	.4	2.0
Windsor	3.0	1.5	1.0	.5	2.5
	6.0	1.1	.8	.3	1.9
	8.0	.9	.7	.2	1.6

TABLE 7--Continued

August

Station	Water Holding Capacity	Mean Moisture Deficiency	Standard Deviation	-1 Standard Deviation*	+1 Standard Deviation**
Woodslee	3.0	1.5	1.2	.3	2.7
	6.0	1.2	1.0	.2	2.2
	8.0	1.0	.8	.2	1.8
		September			
Camlachie	3.0	1.0	.6	.4	1.6
	6.0	.8	.5	.3	1.3
	3.0	.7	.4	.3	1.1
Chatham	3.0	1.0	.9	.1	1.9
	6.0	.9	.8	.1	1.7
	8.0	.7	.7	0	1.4
Forest	3.0	.5	.6	0	1.1
	6.0	.4	.5	0	.9
	8.0	.4	.5	0	.9
Harrow	3.0	1.2	.8	.4	2.0
	6.0	1.0	.7	.3	1.7
	8.0	.9	.6	.3	1.5
Leamington	3.0	1.0	.8	.2	1.8
	6.0	.8	.7	.1	1.5
	8.0	.7	.6	.1	1.3
Oil Springs	3.0	.4	.6	0	1.0
	6.0	.3	.5	0	.8
	8.0	.3	.4	0	.7
Pelee Island	3.0	1.4	.8	.6	2.2
	6.0	1.1	.7	.4	1.8
	8.0	1.0	.6	.4	1.6
Ridgetown	3.0	.9	.9	0	1.8
	6.0	.8	.8	0	1.6
	8.0	.7	.7	0	1.4

TABLE 7--Continued

September

Station	Water Holding Capacity	Mean Moisture Deficiency	Standard Deviation	-1 Standard Deviation*	+1 Standard Deviation**
Sarnia	3.0	.8	.8	0	1.6
	6.0	.6	.6	0	1.2
	8.0	.5	.6	0	1.1
Wallaceburg	3.0	1.0	.8	.2	1.8
	6.0	.8	.6	.2	1.4
	8.0	.7	.6	.1	1.3
Windsor	3.0	.9	.8	.1	1.7
	6.0	.8	.7	.1	1.5
	8.0	.7	.6	.1	1.3
Woodslee	3.0	.9	.6	.3	1.5
	6.0	.7	.6	.1	1.3
	8.0	.6	.5	.1	1.1

* 83.5 per cent of all cases are greater than -1 Standard Deviation.

** 83.5 per cent of all cases are less than +1 Standard Deviation.

The three county area is not a uniform climatic region. The precipitation and potential evapotranspiration vary in a north-south pattern, with the northern section having greater precipitation but less potential evapotranspiration than the south.

Moisture deficiency will vary greatly over the region because of the different water holding capacities of the soils. The low water holding capacity soils in southern Essex County have the greatest moisture deficiency (see Figures 17-22) while the high water holding capacities of northern Lambton County have the least. On a monthly basis July and August, months when crops need sufficient moisture to develop properly, have the highest average moisture deficiency. As shown by various experiments in several sections of the "humid" east, supplemental irrigation can overcome this deficiency and thus increase crop yield.

REFERENCES

[1]Based on available climatological records for stations within the St. Clair Region.

[2]The growing season includes the months May through September, based on the times of planting and the end of growth of the major crops in the St. Clair Region. This is much more significant than using annual statistics because the water balance in months other than during the growing season will have no affect upon the crop production.

[3]The year 1953 was chosen because it had the largest variation in precipitation of any one growing season.

[4]Once the mean and standard deviation are known for a station a distribution can be constructed so that 95 per cent of all the cases will fall within + or - two standard deviations. For example, Harrow has a mean precipitation of 13.9 inches and the standard deviation is 3.4 inches, therefore, 95 per cent of all the years theoretically will have precipitation between 7.1 and 20.7 inches.

[5]Tasseling occurs during the last two weeks of July (from interview with the staff of the Green Giant of Canada, Tecumseh Ontario, office).

[6]H. F. Rhoades and L. B. Nelson, "Growing 100 Bushel Corn with Irrigation" in Water, The Yearbook of Agriculture, ed. Alfred Stefferud (Washington, U. S. Department of Agriculture, 1955), p. 396.

[7]Rhoades and Nelson, p. 396.

[8]Rhoades and Nelson, p. 397.

CHAPTER IV

PERCEPTION OF THE DROUGHT HAZARD

The Sample

The St. Clair Region lies in what has been referred to as the humid east. Despite this title the three county area has often been subjected to yield reducing dry weather. To discover how the farmers of the area perceive the hazard of drought within this region two study areas were chosen. The first was a four square mile section of Colchester South and Colchester North townships, located six miles northeast of Harrow in one of the driest parts of the region. This area was comprised of livestock and cash crop farming. The second area, consisting of fruit and vegetable farmers, extended along highway number 3 from Essex to Ruthven.

Farmers were interviewed by means of a questionnaire made up of three basic parts. The first section dealt with the general information about the farmer and his farm. The second part about how the individual person perceived the hazard of drought or if such a hazard was present. The last section considered how the farmer reacted to the situation. The sample questionnaire appears as Appendix B.

Area I

Only two types of farms were represented in the area, straight grain[1] (47%) and mixed animal and grain with an emphasis on either cattle or pigs

(53%). The farms varied in size from 50 to 150 acres of land.

The study area is further marked by being an area of part time farmers. More than half (53%) of the farmers had supplemental incomes from employment in either Windsor or one of the nearby towns. The remaining 47 per cent with no supplemental income all agreed that animals were necessary if the farm were to be self sufficient. Without the raising of livestock these farmers would also seek other employment.

Results of the questionnaire

Before asking any specific questions on the dangers or degrees of drought in the area each farmer was asked to list the main advantages and disadvantages of his location. Although they had no idea that the main purpose of the questionnaire was to examine their perception of drought in the area, 73 per cent mentioned dry weather as one of the major disadvantages, while 67 per cent mentioned wet springs as being another major disadvantage. The next highest disadvantage, poor drainage was mentioned by only 27 per cent of the farmers. Table 8 shows the disadvantages and advantages listed by the farmers and the number of farmers noting each factor, expressed as a percentage of total farmers.

When asked to list the advantages of the region only 27 per cent listed climate as being an advantage. The two most prominent advantages were listed as level terrain and good transportation facilities.

When interviewing the farmers of the study region, it became apparent that they felt that they were in a dry belt area. The majority, 80 per cent, of the farmers felt that if they were to move a few miles to the

TABLE 8

ADVANTAGES AND DISADVANTAGES
IN CASH CROP AREAS

Advantages	Persons Responding (Per cent)	Disadvantages	Persons Responding (Per cent)
Transportation	47	Dry	73
Terrain	47	Wet	67
Peaceful	33	Drainage	27
Climate	27	Weeds	20
Grain Elevator	27	None	7
Good Drainage	13	Heavy Ground	7
Market	7	Prices Low	7
Central	7	Taxes High	7

north or to the south, but still within Essex County they would be in a more humid area.

The same farmers who felt they were in a dry belt also estimated the percentage of dry years to be greater than the remaining farmers. For comparison, the results of the questionnaire were divided into two groups; group A consisted of the farmers who felt they were in a dry belt and group B of the farmers who did not see a definite dry belt. Both groups were asked how many dry years they would expect out of 25. The average answer for group A was 13 years whereas group B's average answer was 4 years. The two groups were also asked what percentage of the time they would expect a poor crop. Group A's average answer was 35 per cent of the time while group B's average was 13 per cent. When asked what would cause a poor crop everyone in group A mentioned dry weather whereas group B blamed either wet weather or a combination of a wet spring and a dry summer.

Figure 23 shows the study area and the location of farmers in groups A and B. Those in group A were all located from concession six southward and group B were all located but for one exception from concession seven northward. This indicated that there exists in the study area two definite groups of opinion. Farmers in these two groups perceive the danger of crop reducing dry weather to be much greater in the south than in the north.

Despite the fact that group B did not feel they were in a dry belt, all but one felt that yields in their area were reduced because of dry weather. Everyone in group A felt that yields were reduced because of dry weather.

Reaction to drought

Although dry weather was listed as a major cause of crop reduction in the area no farmer used irrigation to overcome this problem. No farmer felt that irrigation would be worth the expense involved.

In 1965 experiments were conducted in Harrow[2] to discover to what extent irrigation could increase the yield of corn. For non-irrigated corn plant populations of 16,000, 22,000, and 28,000 plants per acre the yield was 111, 104, and 98 bushels per acre respectively. When irrigated, these same plant populations produced 149, 177, and 175 bushels per acre respectively.[3] This points out two factors: irrigation will result in substantially higher yields of corn per acre, and its effectiveness will depend upon the type of crop management. For the three plant populations used in the Harrow experiments and using a market value of $1.27[4] per bushel, the increased value of the corn crop in the three cases would be $48, $92, and $97 per acre respectively. This would result in an increase of $4,826, $9,271, and $9,779 for a

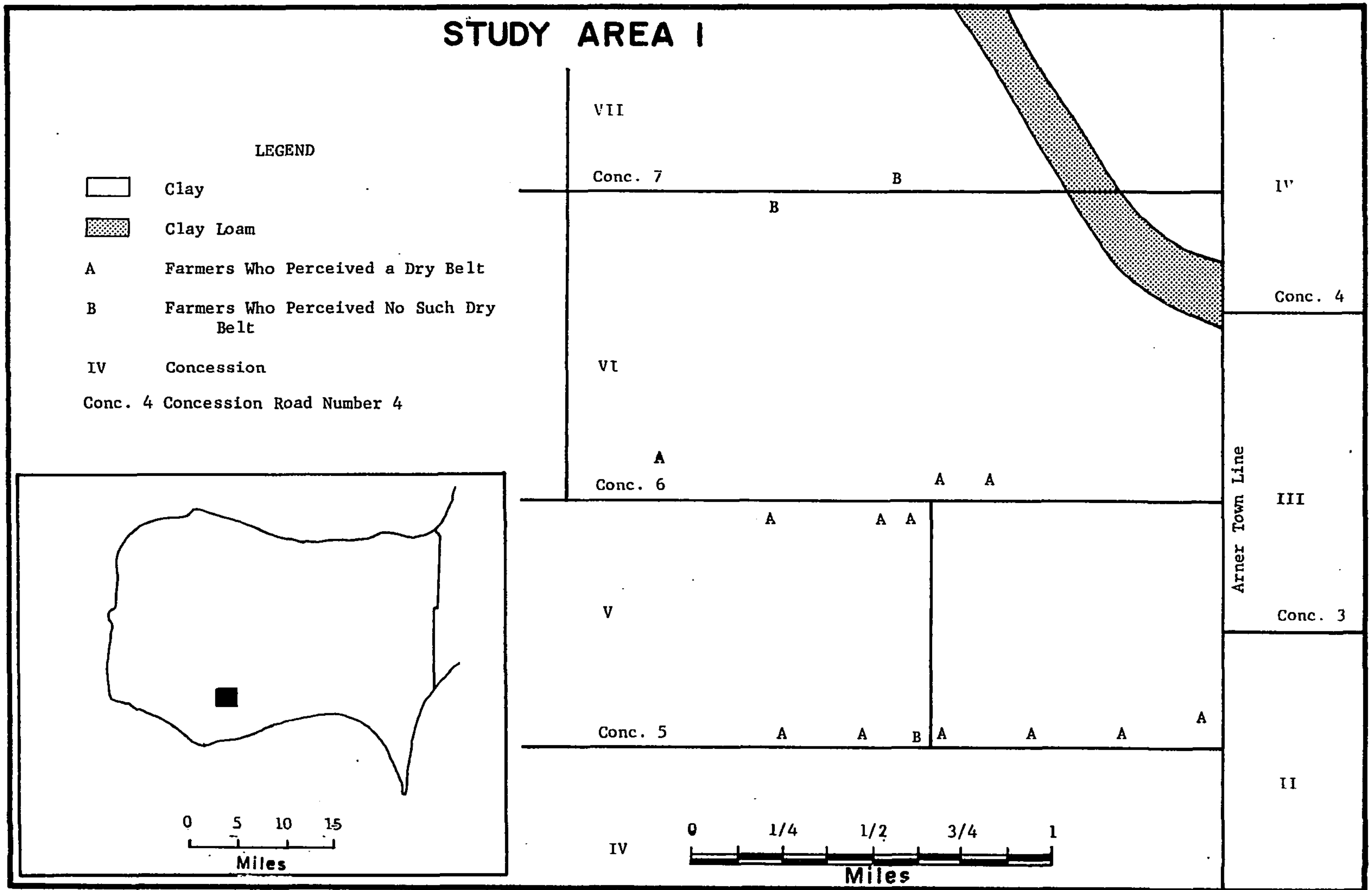

STUDY AREA I
LEGEND
Clay
Clay Loam
A Farmers Who Perceived a Dry Belt
B Farmers Who Perceived No Such Dry Belt
IV Concession
Conc. 4 Concession Road Number 4
VII
Conc. 7
VI
Conc. 6
V
Conc. 5
IV
III
II
Conc. 4
Conc. 3
Arner Town Line
0 5 10 15
Miles
0 1/4 1/2 3/4 1
Miles

Figure 23

100 acre farm, the average in the area surveyed.

Statistics for increased yields of corn resulting from irrigation are available for only the one year--1965. Further experiments however have been completed[5] and have shown that with a higher moisture deficiency the benefit of irrigation is greatest. As moisture deficiency becomes less, the increase in yield because of irrigation becomes less. The moisture deficiency figures for 1965 were compared to the 28 year period of record to discover if 1965 was an exceptionally dry year which would in turn give exceptionally high values for increases in yields because of irrigation. Table 9 summarizes the results. The 1965 figures did not show an exceptionally dry year. For the months of May, June and July the moisture deficiency over the 28 year period of study was equal to or greater than the 1965 figure in approximately 40 per cent of the cases. For August and September the figure was much higher with greater than 80 per cent of the cases being equal to or greater than the 1965 data.

The results indicate that irrigation would greatly increase the crop yields in the area. Although the farmers in the study area felt that irrigation was too expensive,[6] the possibility of increasing the value of farm production by more than $9,000 may tilt the balance in favour of irrigation.

Area II

The farms in area II (see Figure 24) were divided into three categories; fruit (13%), vegetables (27%), and a mixture of fruit and vegetables (60%), with acreages ranging from 4 to 79 acres.

STUDY AREA II

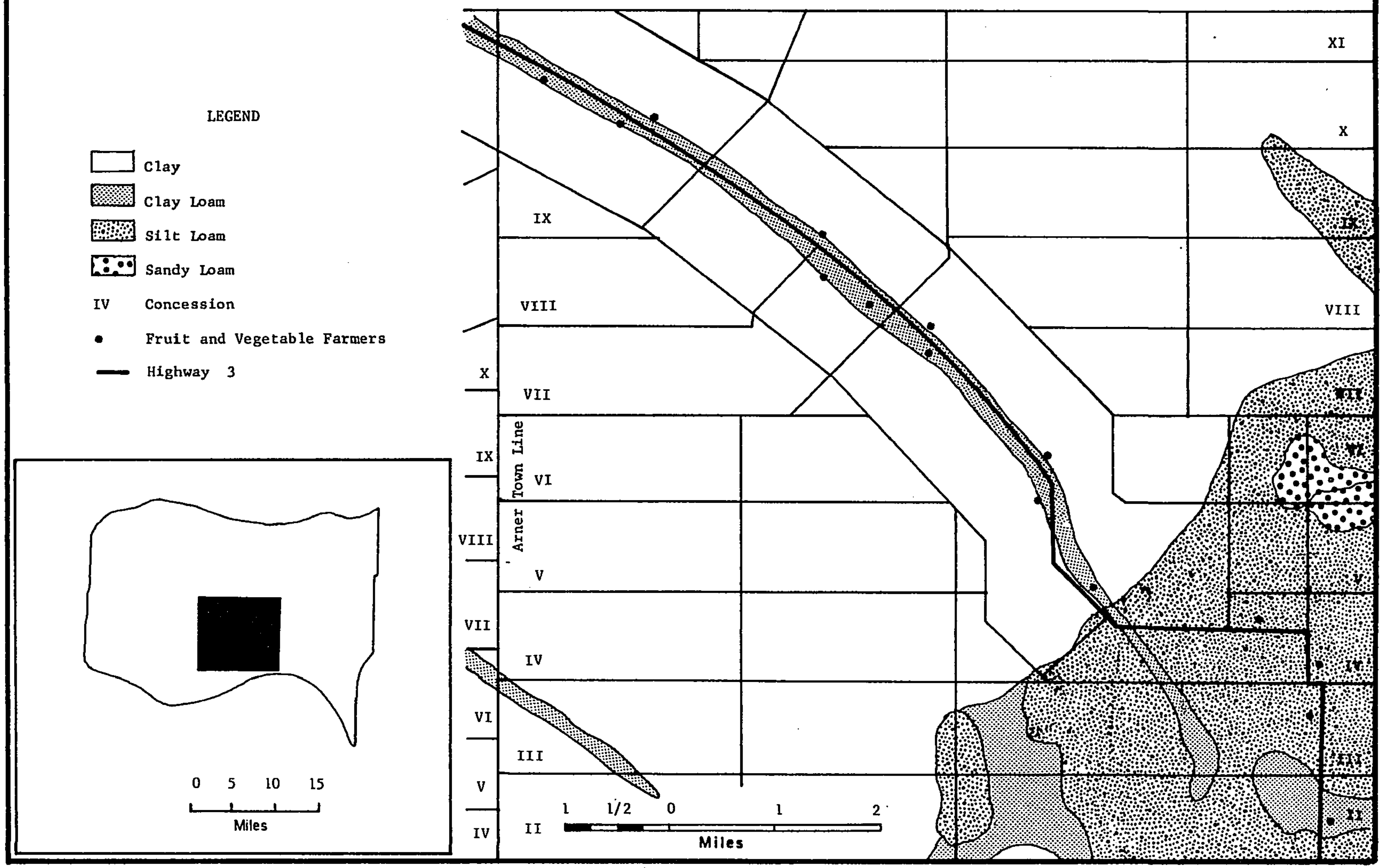


Figure 24

Contrary to area I the fruit and vegetable growers were predominantly full time farmers (73%). The 27 per cent classified as part time farmers all felt that a large scale operation required too great a financial investment, while lacking sufficient returns.

Table 9

COMPARISON OF 1965 MOISTURE DEFICIENCY TO AVERAGE CONDITIONS

Time Period	Moisture Deficiency 1965* (Inches)	Moisture Deficiencies =1965 (Per cent)**
Growing Season	2.97	78.6
May	.09	39.3
June	.75	39.3
July	1.83	42.9
August	0	85.7
September	.30	82.2

* Using water holding capacity = 6.0 inches.

** Based on 28 year record at Harrow.

Results of the questionnaire

The same procedure of interviewing was used as in area 1. Again dry weather was the dominant factor listed by the farmers, with 60 per cent noting dry summers as a major problem. The second greatest disadvantage also agreed with area I as 47 per cent listed wet springs as a major problem. Table 10 shows the advantages and disadvantages listed by the farmers in area II.

Climate was listed by 40 per cent of the fruit and vegetable growers as being an advantage. The advantage was not because of a moisture factor, but rather because the growing season began earlier in Essex County than the rest of the province, allowing the Essex County fruit and vegetable growers to have their products on the market first.

Table 10

ADVANTAGES AND DISADVANTAGES IN FRUIT AND VEGETABLE AREAS

Advantages	Persons Responding (Per cent)	Disadvantages	Persons Responding (Per cent)
Good Soil	60	Dry	60
Good Climate	40	Wet	47
Location	40	Weeds	33
Peaceful	20	Taxes	33
Level Terrain	13	Low Prices	33
		Insects	7
		Hail	7

Good soil (sand and loam) and location were also listed as primary advantages of the area. These two factors were the main reasons listed for choosing the present sites of the full time fruit and vegetable growers. The farmers felt that good soil was essential for producing top quality products. Location along a main highway was also listed as necessary since the farmers depended heavily upon sale of their produce at roadside stands.

Reaction to drought

The farmers of Area II, although not being more aware of the danger of drought than the farmers in Area I, were much more willing to invest in irrigation equipment. Almost half (43%) of the fruit and vegetable growers used irrigation. Only two stated they would not like to use irrigation, not because they did not recognize the value of irrigation in increasing crop yield but rather because their farms were not large enough to warrant the expense involved in setting up an irrigation system.

Experiments at Harrow[7] have confirmed the general view expressed by the fruit and vegetable growers that irrigation was necessary to produce maximum yields. Controlled experiments at Harrow have shown that the yields of cucumbers can be doubled and potatoes tripled by use of supplemental irrigation. Over a period of 11 years irrigated potatoes averaged 317 bushels per acre, while the non-irrigated crops averaged only 195 bushels per acre.[8]

In 1965 experiments were also undertaken to discover the possible increase in yield through irrigation. The irrigated crop produced 306 bushels of marketable potatoes and the non-irrigated plot only 160 bushels.[9] Using a market value of $1.10 per bushel[10] the increased value of the potato crop in the experiment would be $161 per acre or $4,508 for 28 acres (the average size of the farms in the Area II) well above the estimated cost of irrigating a farm of the same size.[11]

Summary

Both grain farmers and fruit and vegetable growers recognize the danger of dry weather affecting their crops. The reaction of the two groups however is much different. The cash crop farmers expect their crop yields to be reduced but feel that the expense involved in an irrigation network would not be offset by increased profits. The fruit and vegetable growers are more willing to invest in an irrigation system.

The reasons for the different reaction to the threat of drought became apparent after talking to the various farmers. The major reasons were all a matter of economics. The fruit and vegetable growers receive a greater increase in profit per unit area irrigated than do the grain farmers e.g. $161 per acre potatoes compared to $97 per acre for corn as shown by experiments at Harrow. This greater increase in profits per acre for the fruit and vegetable growers is more likely to overcome the cost of irrigation than would be the case for the farmers growing grain. Secondly, the fruit and vegetable growers are more often full time farmers and therefore cannot afford to absorb the losses that a part time farmer can. The third major factor is that the farms in Area II are much smaller than those in Area I and therefore irrigation systems would be less costly to install and to operate.

REFERENCES

[1]Any combination of corn, wheat and beans.

[2]J. M. Fulton, "Soil Moisture for Crop Production Canada Agriculture, (Winter, 1967), 1-3.

[3]Fulton, p. 1.

[4]*Agricultural Statistics for Ontario*, 1967, Ontario Department of Agriculture and Food, (Toronto, 1968), p. 50.

[5]From conversation with Dr. J. M. Fulton.

[6]The cost of irrigation will vary greatly, depending upon source of water, type of irrigation project and frequency of irrigation needs. For the Great Lakes Region V. Rutten arrived at an average cost of irrigation to be $62 per acre using irrigation equipment costs (interest, depreciation, taxes, insurance, and repairs) but not including costs of labour or operating expenses. This would result in a cost of $6,200 per 100 acre farm plus labour and operating expenses. This figure would be greatly increased if water is not readily available, as in the case in many parts of the St. Clair Region.

[7]Fulton, p. 1

[8]*Ibid*.

[9]*Ibid*.

[10]*Agricultural Statistics*, p. 48.

[11]Using the same figures for cost of irrigation (see footnote 6) the average cost to irrigate a 28 acre fruit and vegetable farm would be $1,736.

CHAPTER V

CONCLUSIONS

The present study attempts a quantification of drought in the St. Clair Region. To quantify drought, the climatic factors, moisture holding capacities of the soil, the crop and various cultivation practices must be considered. The maps and tables presented here are for moderately deep-rooted crops, e.g. corn, in the St. Clair Region, but do not attempt to include various cultivation practices.

One of the major contributions of the study is the map (Figure 3) of the water holding capacities of the soils of the region for moderately deep-rooted crops.

The climatic statistics of all available climatic stations are analyzed using a water balance model, stressing the growing season data. Tables and maps are presented showing the amount and variation in the heat factor, or potential evapotranspiration, the precipitation and the moisture deficiency. The maps of the region showing seasonal and average monthly deficiency for each soil type could be of major practical value for irrigation purposes in the region.

A preliminary investigation into the perception of the drought hazard, only in the Essex County area, indicated that the farmers were well aware of the yield reducing effects of invisible drought. Whether they practiced irrigation was found to be a matter of economics. Experiments at the Federal Research Station at Harrow indicate a relationship between irrigation and increased yields, and increasing yields with irrigation under conditions of greater natural deficiency. The complex relationship of yield to drought or to irrigation added with different cultivation practices, has not been attempted here.

The study suggests many more tasks which should be attempted. Similar maps and tables should be constructed for other types of crops, shallow-rooted, deep-rooted, and orchards. The effects of various cultivation practices, e.g. the spacing of rows, the number of plants per acre, the amount of fertilization and tillage on the use of water must be considered. In addition, even with the perception of the drought hazard and the willingness to invest in irrigation equipment by the farmers of the area, optimum irrigation practices must be studied. Only when these tasks have been completed can a drought model for the St. Clair Region be attempted.

Finally, a much more comprehensive coverage of the area with rainfall stations would permit a more accurate description of drought in this region, too often considered to be geographically uniform, but in reality of great diversity in climate and soils.

APPENDIX A

Water Balance Program

```
C     THIS PROGRAM COMPUTES THE AVERAGE WATER BALANCE BY MONTHS,
C     FOR AS MANY CONSECUTIVE YEARS AS DESIRED.
C
C     INPUT ITEMS AS FOLLOWS.
C       CARD 1      COL    1-4    YEAR AT START OF DATA.
C                   COL    5-76   STATION IDENTITY.  ANY CONVENIENT FORM.
C       CARD 2 THRU CARD 5 UNADJUSTED PE VALUES FOR SOME 1 VALUE.
C                          THERE ARE 137 VALUES PUNCHED 40 PER CARD,
C                          STARTING AT 32 DEGREES AND GOING BY HALF
C                          DEGREES TO TO 100 DEGREES.
C       CARD 6      COL    1-60 MONTHLY DURATION OF SUNLIGHT TABLES FOR THE
C                             STATION LATITUDE.  TWELVE VALUES IN FIVE
C                             COLUMN FIELDS, WITH DECIMAL POINTS.
C
C     FOLLOWING ARE TWO CARD PAIRS, ONE PAIR FOR EACH YEAR OF DATA.
C       FIRST CARD OF PAIR HAS TWELVE MONTHLY AVERAGE TEMPERATURES
C       PUNCHED IN FIVE COLUMN FIELDS, WITH DECIMAL POINT.
C       SECOND CARD OF PAIR HAS TWELVE MONTHLY AVERAGE PRECIPITATION
C       VALUES IN FIVE COLUMN FIELDS, WITH DECIMAL POINTS.
C
C     FOLLOWING THE LAST PAIR OF T-P VALUES, THERE SHOULD BE A PAIR
C     OF BLANK CARDS TO SIGNIFY THE END OF A SET OF DATA.
C     THE PROGRAM IS SET TO PROCESS MULTIPLE SETS OF DATA, UNTIL
C     NO MORE CARDS ARE AVAILABLE.
C
      DIMENSION U(137),C(12),W(13,12),T(12),P(12),TITLE(12)
    2 CONTINUE
      WHC = 08.0
      QST = WHC
      SUM=0.0
      ROS = 0.0
      READ 906, IYR,TITLE
      PUNCH 903,TITLE
    1 READ 901, U
      READ 902, C
    5 W(7,12) = WHC
   10 CONTINUE
      READ 902, T
      READ 902, P
      IF (T(7)) 30,20,30
   20 GO TO 2
   30 STL = W(7,12)
```

```
    DO 250 J = 1,12
    W (1,J) = T (J)
    W (2,J) = 0.0
 35 W (4,J) = P (J)
    W (11,J) = 0.0
    W (12,J) = 0.0
    IF (T(J)-32.0) 50,40,40
 40 IT = 2.0*(J)-62.5
    W(2,J) = U(IT)
 50 W(3,J) = W(2,J)*C(J)
    W(5,J) = W(4,J)-W(3,J)
    W(6,J) = 0.0
    IF (W(5,J)) 60,70,70
 60 CONTINUE
    IF (QST-WHC) 65,65,63
 63 W(11,J) = QST-WHC
 65 CONTINUE
    SUM = SUM + W(5,J)
    W(6,J) = SUM
    W(7,J) = WHC*EXPF(SUM/WHC)
    W(8,J) = W(7,J) -QST
    QST = W(7,J)
    W(9,J) = W(4,J) -W(8,J)
    W(10,J) - W(3,J) -W(9,J)
    GO TO 200
 70 CONTINUE
    W(7,J) = STL + W(5,J)
    W(9,J) = W(3,J)
    W(10,J) = 0.0
    IF (W(7,J)-WHC) 80,115,90
 80 CONTINUE
    SUM = WHC*LOGF(W(7,J)/WHC)
    W(6,J) = SUM
    W(8,J) = W(7,J)-QST
    QST = W(7,J)
    GO TO 200
 90 CONTINUE
    SUM = 0.0
    W(6,J) = 0.0
    W(8,J) = WHC-QST
    QST = WHC
    IF(T(J)-31.0) 200,200,110
110 CONTINUE
    W(7,J) = WHC
115 CONTINUE
    W(11,J)=W(5,J)+STL-W(7,J)
200 CONTINUE
220 IF (J-1) 230,230,240
230 DO 235 1=1,12
235 W(13,1) = 0.0
240 DO 245 1 = 1,11
```

```
245 W(13,1) = W(1,J)+W(13,1)
    STL = W(7,J)
    W(12,J) = 0.5*(ROS+W(11,J))
    ROS = W(12,J)
250 CONTINUE
    W(13,1) = W(13,1)/12.
    W(13,7) = W(13,7)/12.
    DO 270 1 = 1,13
    DO 265 J = 1,12
265 T(J) = W(1,J)
    PUNCH 904, T,IYR,1
270 CONTINUE
    PUNCH 905
    IYR = IYR + 1
    GO TO 10
901 FORMAT (40F2.2)
902 FORMAT (12F5.2)
903 FORMAT(1H1,12A6)
904 FORMAT (12F6.2,15,13)
905 FORMAT (1H )
906 FORMAT (14,12A6)
    END
```

APPENDIX B

Questionnaire

1. How long have you been farming in this area?_____Years

   If all my life: How long has your family been in the area?_____Years

2. Are you a part time or full time farmer?

   (a) Part time__________
   (b) Full time__________

   If part time where do you work?__________

3. What is the exact nature of your operation?

   Fruit__________
   Vegetable__________
   Combination fruit and vegetable__________
   Straight grain__________
   Diversified (grain emphasis)__________
   Diversified (livestock interest)__________
   Other (Specify)__________

4. How much land do you have? Number of acres______

5. What are the main advantages or disadvantages of this area?

   Advantages:

   Good Climate__________
   Good Drainage__________
   Good Soil__________
   Level Terrain__________
   Transportation__________
   Other__________

   Disadvantages:

   Too Dry__________
   Too Wet__________
   Poor Drainage__________
   Poor Soil__________
   Other__________

6. Would you consider yourself to be in a Dry Belt?

   Yes_____
   No_____

7. Does dry weather affect crop yields in this area?__________

Does wet weather affect crop yields in this area?__________

8. How many dry years would you expect out of 25?

25_____ 20_____ 15_____ 10_____ 5_____ Other_____

9. How often to you expect a poor crop?

Every year__________ 75%__________ 50%__________

25%__________ 10%__________ Other__________

If the crop is poor, most frequent causes: 1.__________

2.__________

3.__________

10. Do you use irrigation? Yes_____ No_____

If yes, when did you start?_____ How often_____

If no, would you like to? Yes_____ No_____

What prevents you? Too expensive_____ No water_____

Other_______________

BIBLIOGRAPHY

Agricultural Statistics for Ontario, 1967. Publication No. 20, Toronto: Ontario Department of Agriculture and Food, 1968.

Barger, G. L., and Thom, H. C. S. "Evaluation of Drought Hazard," *Agronomy Journal*, XLI (1949), 519-26.

Barger, Gerald L. and Thom, H. C. S. "A Method for Characterizing Drought Intensity in Iowa," *Agronomy Journal*, XLI (1949), 13-19.

Bavel, C. H. M. van and Verlinden, F. J. *Agricultural Drought in North Carolina*. North Carolina State College Agricultural Experimental Station, Technical Bulletin No. 122. (1956).

Bavel, C. H. M. van. "Drought Criterion and its Application in Evaluating Drought Incidence and Hazard," *Agronomy Journal*, XLV (1953), 167-72.

Blayney, H. F., and Criddle, W. D. *Determining Water Requirements in Irrigated Areas from Climatological and Irrigation Data*, United States Department of Agriculture Soil Conservation Service, SCS-TP-96, (1950).

Businger, J. S. "Some Remarks on Penman's Equations for the Evapotranspiration," *Netherlands Journal of Agricultural Science*, IV (1956), 77-80.

Clark, Colin. *The Economics of Irrigation*, London: Pergamon Press, 1967.

Denmead, O. T. and Shaw, R. H. "Availability of Soil Water to Plants as Affected by Soil Moisture Content and Meteorological Conditions," *Agronomy Journal*, LIV (1962), 385-90.

Denmead, O. T., and Shaw, R. H. "Evapotranspiration in Relation to the Development of the Corn Crop, *Agronomy Journal*, LI (1959), 725-26.

Fieldhouse, D. J. and Palmer, W. C. *Meteorological and Agricultural Drought*, Deleware Agricultural Experimental Station Bulletin No. 353 (1965), 1-71.

Fitzgerald, P. D. and Rickard, D. S. "A Comparison of Penman's and Thornthwaite's Method of Determining Soil Moisture Deficits," *New Zealand Journal of Agricultural Research*, III (1966), 106-12.

Fulton, J. M. "Soil Moisture for Crop Production," *Canada Agriculture*, Repring (Winter, 1967), 1-2.

Gardner, W. R. and Ehlig C. F. "The Influence of Soil Water on Transpiration by Plants," Journal of Geophysical Research, LXVIII (1963), 5719-24.

Harris, D. G., and Van Bavel, C. H. M. "A Comparison of Measured and Computed Evapotranspiration from Bermuda-Grass and Sweet Corn," Agronomy Abstracts, (1958).

Headley, J. C. "Factors Associated with the Location of Supplemental Irrigation in the Humid Area," Land Economics, XXXVIII (May, 1961)

Hylckama, T. E. A. van. "The Water Balance of the Earth," Publications in Climatology, IV (1956), 53-117.

Kopec, Richard J. "An Alternative Method for the Construction of Thiessen Polygons" The Professional Geographer, XV No. 5 (September, 1963), 24-26.

Kramer, P. J. "The Role of Water in the Physiology of Plants," Advances in Agronomy, XI (1959), 51-70.

Kramer, P. J. "Discussion of F. J. Veihmeyer and A. H. Hendrickson," Transactions of the American Geophysical Union, XXXVI (1955), 438-39.

Mather, J. R. "Discussion of F. J. Veihmeyer and A. H. Hendrickson," Transactions of the American Geophysical Union, XXXVI (1955) 434-35.

Monthly Record. Toronto: Department of Transport, Meteorological Branch, 1940-1967.

Palmer, Wayne C. "Meteorological Drought," U. S. Weather Bureau Research Paper No. 45. Washington: U. S. Department of Commerce, February, 1965.

Palmer, W. C. "Moisture Variability and Drought Severity, "Proceedings of the Agricultural Research Institute, U. S. A., (1964), 145-57.

Palmer, Wayne C. "Weekly Weather and Crop Bulletin" U. S. Weather Bureau, XIIV, No. 1a (January 10, 1957), 1.

Pelton, W. L. "The Use of Lysimetric Methods to Measure Evapotranspiration," Proceedings of Hydrology Symposium, No. 2, Evaporation, (1961), 106-122.

Pelton, W. L., King, K. M., and Tanner, C. B. "An Evaluation of the Thornthwaite and Mean Temperature Methods for Determining Potential Evapotranspiration," Agronomy Journal, LII (1960), 387-95.

Penman, H. L. "The Dependence of Transpiration on Weather and Soil Conditions," Journal of Soil Science, I (1949), 74-89.

Penman, H. L. "Evaporation: An Introductory Survey," Netherlands Journal of Agricultural Science, IV (1956), 8-29.

Penman, H. L. "Natural Evaporation from Open Water, Bare Soil and Grass," Proceedings of the Royal Society, CXCIII (1948), 120-45.

Penman, H. L. and Long, I. F. "Weather in Wheat: An Essay Micro-meteorology," Journal of the Royal Meteorological Society Quarterly, LXXXVI (1960), 16-50.

Pistor, Val. A Climatological Approach to Irrigation Scheduling: A Comparison of Three Methods of Computing Water Use. Windsor: University of Windsor, 1967.

Rhoades, H. F. and Nelson, L. B. "Growing 100 Bushel Corn With Irrigation," in ed. Alfred Stefferud, Water The Yearbook of Agriculture. Washington: U. S. Department of Agriculture, 1955.

Richards, L. A. and Wadleigh, C. H. "Soil Water and Plant Growth," in B. T. Shaw (ed.), Soil Physical Conditions and Plant Growth. New York: Academic Press, 1952.

Ruttan, Vernon W. The Economic Demand for Irrigated Acreage. Baltimore, Maryland: The Johns Hopkins Press, 1965.

Sanderson, M. E. "Observations of Potential Evapotranspiration at Windsor," Publications in Climatology, VII (1954), 91-93.

Slatyer, R. O. "The Influence of Progressive Increases in Total Soil Moisture on Transpiration, Growth and Internal Water Relationships of Plants," Australian Journal of Biological Science, X (1957), 320-36.

Slatyer, R. O. "The Significance of the Permanent Wilting Percentage in Studies of Plant and Soil Water Relations," Botany Review, XXXIII (1957), 585-636.

Smith, G. W. "The Determination of Soil Moisture Under a Permanent Grass Cover," Journal of Geophysical Research, LXIV (1959), 477-483.

Soil Map of Kent County. Report No. 3. Toronto: Ontario Department of Agriculture and Food, 1937.

Soil Survey of Essex County. Report No. 11. Toronto: Ontario Department of Agriculture and Food, 1947.

Soil Survey of Lambton County. Report No. 22. Toronto: Ontario Department of Agriculture and Food, 1957.

Stanhill, G. "The Effect of Differences in Soil-moisture Status on Plant Growth: a Review and Evaluation," Soil Science, LXXXIV (1957), 205-14.

Stearns, F., and Carlson, C. A. Correlations Between Solar Radiation and Other Environmental Factors and Soil Moisture Depletion, Presented 40th Annual Meetings of American Geophysical Union, Washington, D. C., 1959.

Stefferud, Alfred, ed. Water, The Yearbook of Agriculture. Washington: U. S. Department of Agriculture, 1955.

Tannehill, I. R. Drought: Its Causes and Effects. Princeton: Princeton University Press, 1947.

Tanner, C. B., and Pelton, W. L. "Potential Evapotranspiration Estimates by the Approximate Energy Balance Method of Penman," Journal of Geophysical Research, LXV (1960), 3391-413.

Thomas, H. E. "General Summary of Effects of the Drought in the Southwest," Geological Survey Professional Paper 372-H. Washington: U. S. Government Printing Office, 1963.

Thompson, M. L. "Weather Influences on Corn Yields," Proceedings of the Agricultural Research Institute, (1964), 113-31.

Thornthwaite, C. W. "An Approach Toward a Rational Classification of Climate," Geographical Review, XXXVIII (1948), 55-94.

Thornthwaite, C. W. "Report of the Commitee on Transpiration and Evaporation, 1943-44," Transactions of the American Geophysical Union, XXVI (1944), 683-93.

Thornthwaite, C. W., and Holzman, B. "Measurement of Evaporation from Land and Water Surfaces," U. S. Department of Agriculture, Technical Bulletin No. 817, (1942).

Thornthwaite, C. W., and Mather, J. R. "Instructions and Tables for Computing Potential Evapotranspiration and the Water Balance," Publications in Climatology, X (1957), 185-311.

Thornthwaite, C. W. and Mather, J. R. "The Water Balance" Publications in Climatology VIII No. 1, 1955, 1-104.

Thornthwaite C. W., and Mather J. R. "The Water Budget and its Use in Irrigation," in ed. Alfred Stefferud, Water, The Yearbook of Agriculture. Washington: U. S. Department of Agriculture, 1955.

Thornthwaite, C. W., Mather, J. R. and Carter, D. B. Three Water Balance Maps of Eastern North America. New York: Resources for the Future Inc., 1958.

Veihmeyer, F. J. "Soil Moisture," Encyclopedia of Plant Physiology, III (1956), 64-123.

Veihmeyer, F. J., and Hendrickson, A. H. "Does Transpiration Decrease as the Soil Moisture Decreases?" Transactions of the American Geophysical Union, XXXVI (1955), 425-28.

Veihmeyer, F. J., and Hendrickson, A. H. "Soil Moisture in Relation to Plant Growth," Plant Physiology, Annual Review, I (1950), 285-304.

VITA

Name: Ronald C. A. Johnson

Born: June 18, 1944

Place: Harrow, Ontario, Canada

Elementary School: S.S. #18 Colchester South, 1950-1958

High School: Harrow District High School, 1958-1963

University: University of Windsor, B.A., 1966

NOTE TO USERS

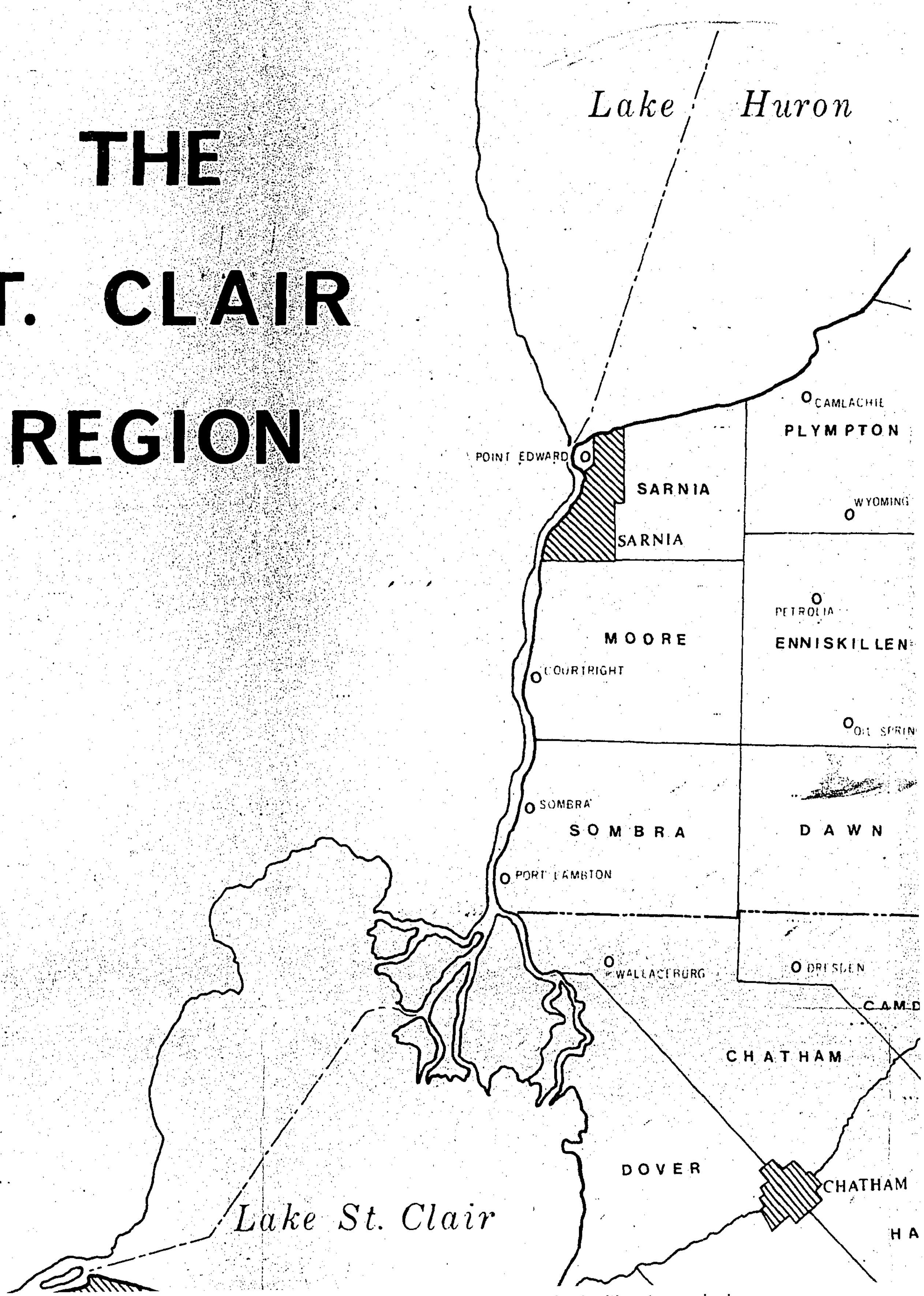
Oversize maps and charts are microfilmed in sections in the following manner:

LEFT TO RIGHT, TOP TO BOTTOM, WITH SMALL OVERLAPS

This reproduction is the best copy available.

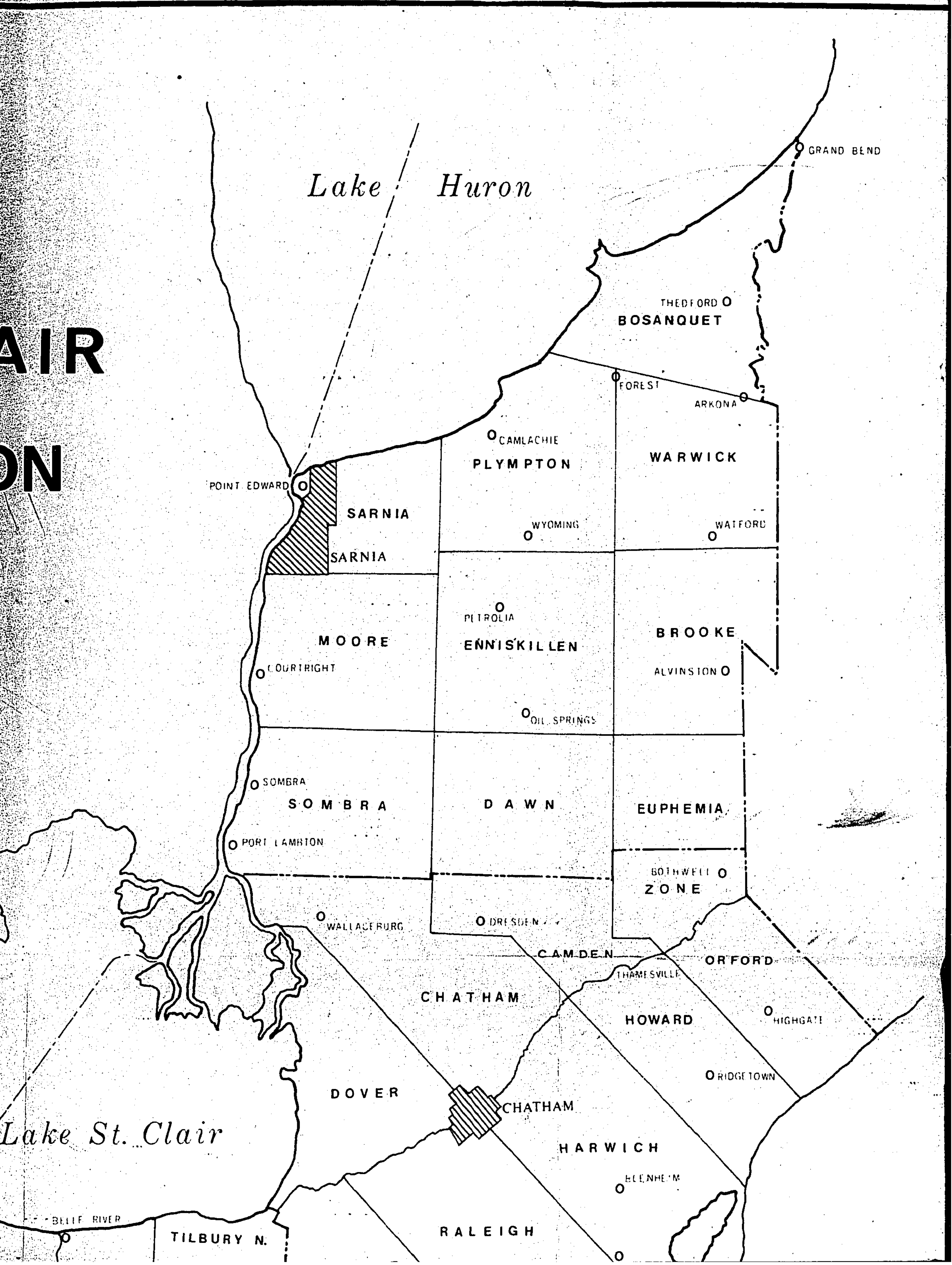
UMI®

THE ST. CLAIR REGION



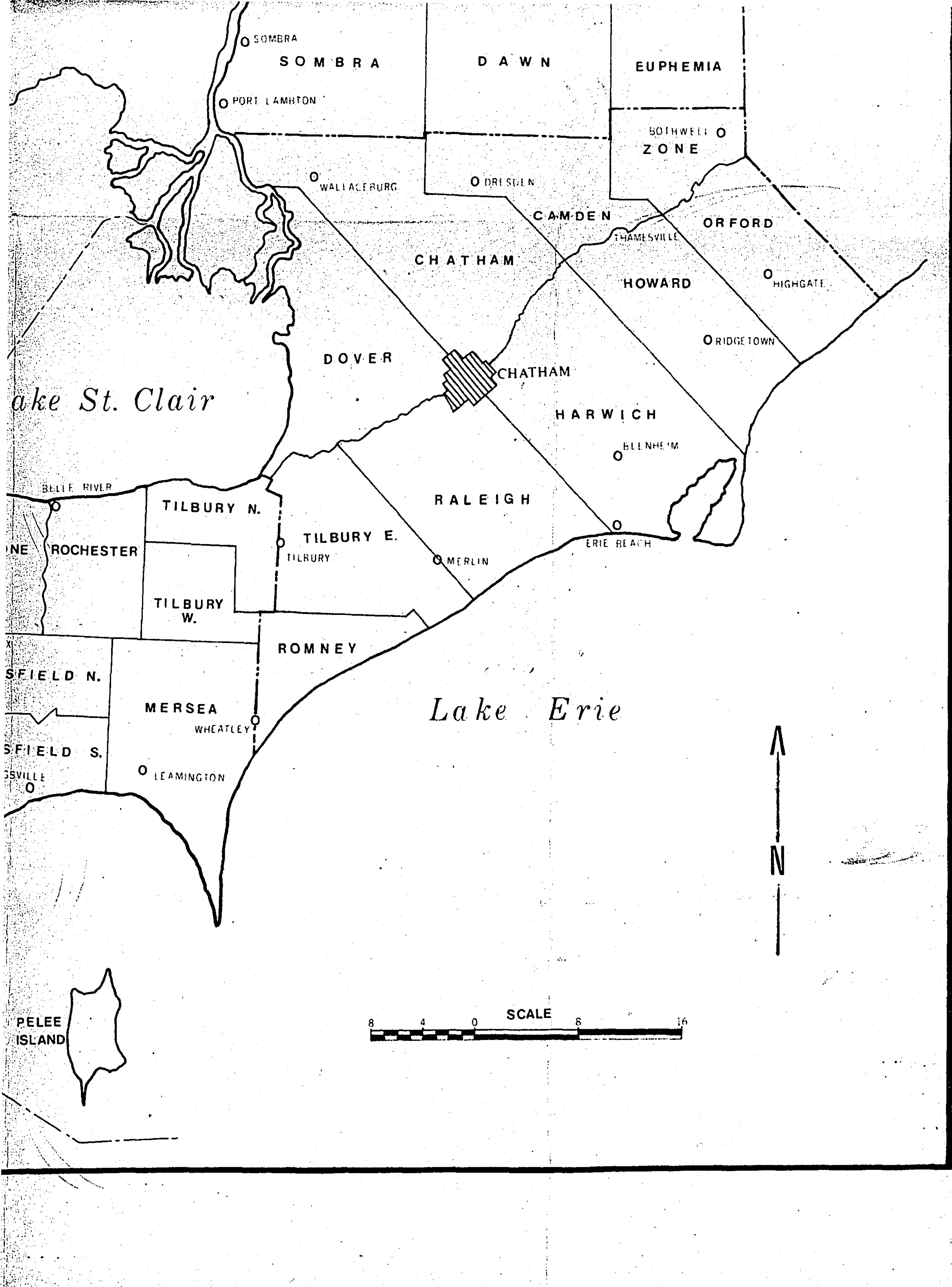
AIR

ON



Lake Huron
GRAND BEND
THEDFORD
BOSANQUET
FOREST
ARKONA
CAMLACHIE
PLYMPTON
WARWICK
POINT EDWARD
SARNIA
SARNIA
WYOMING
WATFORD
PETROLIA
MOORE
ENNISKILLEN
BROOKE
COURTRIGHT
ALVINSTON
OIL SPRINGS
SOMBRA
SOMBRA
DAWN
EUPHEMIA
PORT LAMBTON
BOTHWELL
ZONE
WALLACEBURG
DRESDEN
CAMDEN
THAMESVILLE
ORFORD
CHATHAM
HOWARD
HIGHGATE
RIDGETOWN
DOVER
CHATHAM
Lake St. Clair
HARWICH
BLENHEIM
BELLE RIVER
TILBURY N.
RALEIGH


SOMBRA
SOMBRA
DAWN
PORT LAMBTON
WALLACEBURG
DRESDEN
CAMDE
CHATHAM
DOVER
CHATHAM
HAR
Lake St. Clair
BELLE RIVER
TILBURY N.
RALEIGH
WINDSOR
MAIDSTONE
ROCHESTER
TILBURY E.
TILBURY
MERLIN
LA SALLE
SANDWICH W.
SANDWICH S.
TILBURY W.
ESSEX
ROMNEY
ANDERDON
COLCHESTER N.
GOSFIELD N.
MERSEA
Lake Er
AMHERSTBURG
WHEATLEY
MALDEN
GOSFIELD S.
COLCHESTER S.
KINGSVILLE
LEAMINGTON
HARROW
PELEE ISLAND
SCALE
8 4 0 8



SOMBRA
SOMBRA
DAWN
EUPHEMIA
PORT LAMBTON
BOTHWELL
ZONE
WALLACEBURG
DRESDEN
CAMDEN
ORFORD
THAMESVILLE
CHATHAM
HOWARD
HIGHGATE
RIDGETOWN
DOVER
CHATHAM
ake St. Clair
HARWICH
BLENHEIM
BELLE RIVER
TILBURY N.
RALEIGH
TILBURY E.
ERIE BEACH
NE
ROCHESTER
TILBURY
MERLIN
TILBURY W.
ROMNEY
SFIELD N.
MERSEA
Lake Erie
WHEATLEY
SFIELD S.
SSVILLE
LEAMINGTON
N
PELEE ISLAND
SCALE
8
4
0
8
16

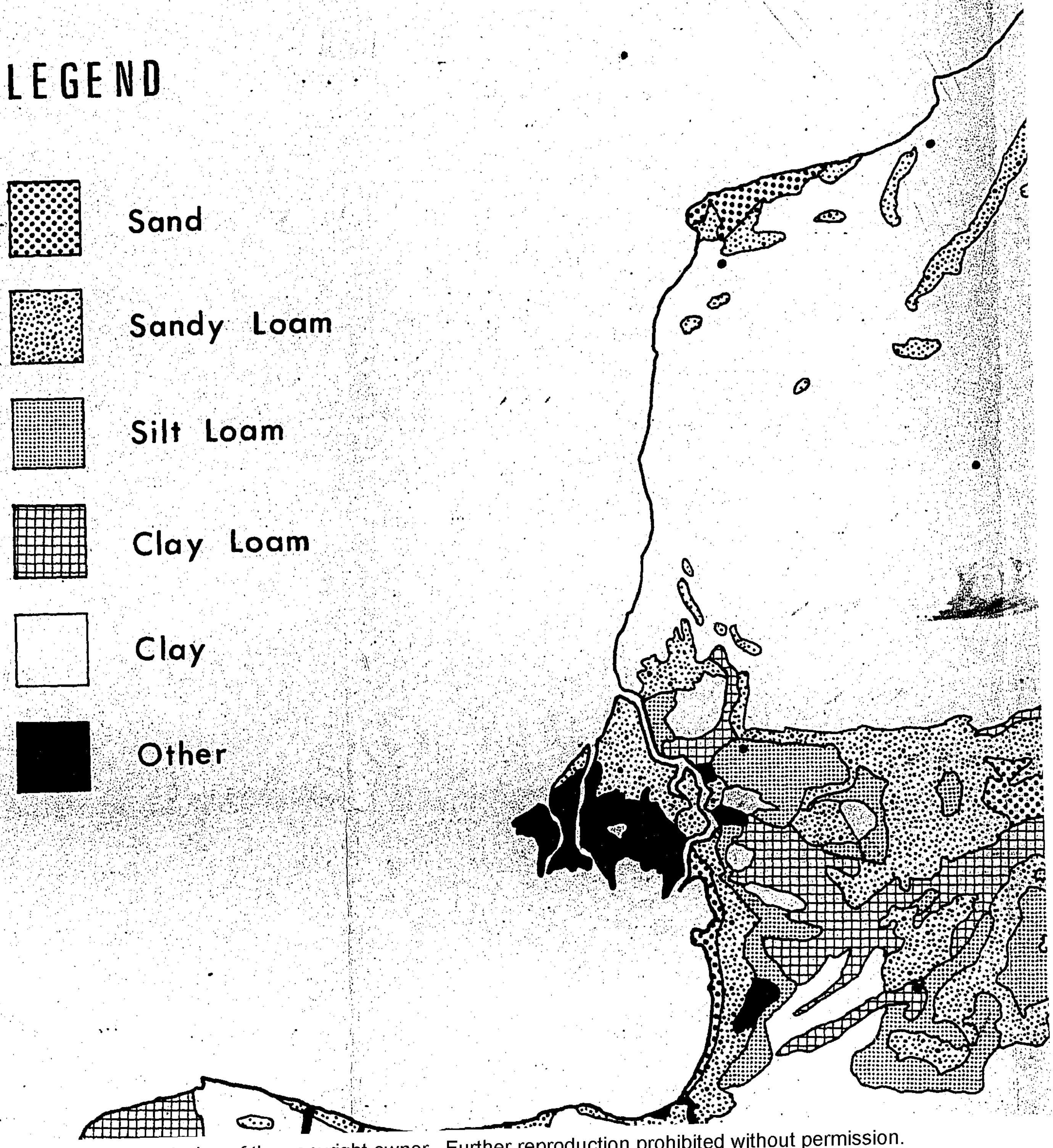
NOTE TO USERS

Oversize maps and charts are microfilmed in sections in the following manner:

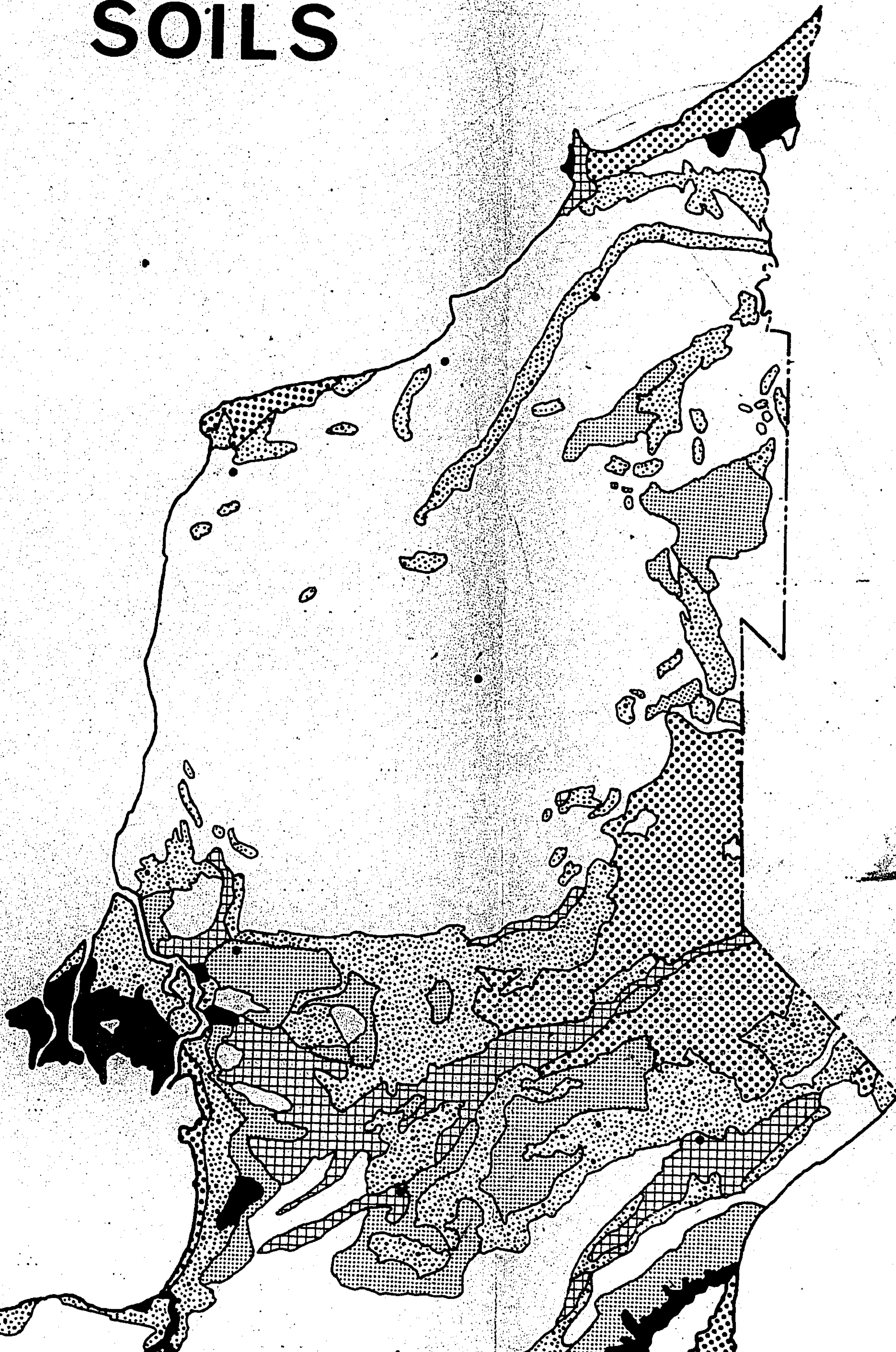
LEFT TO RIGHT, TOP TO BOTTOM, WITH SMALL OVERLAPS

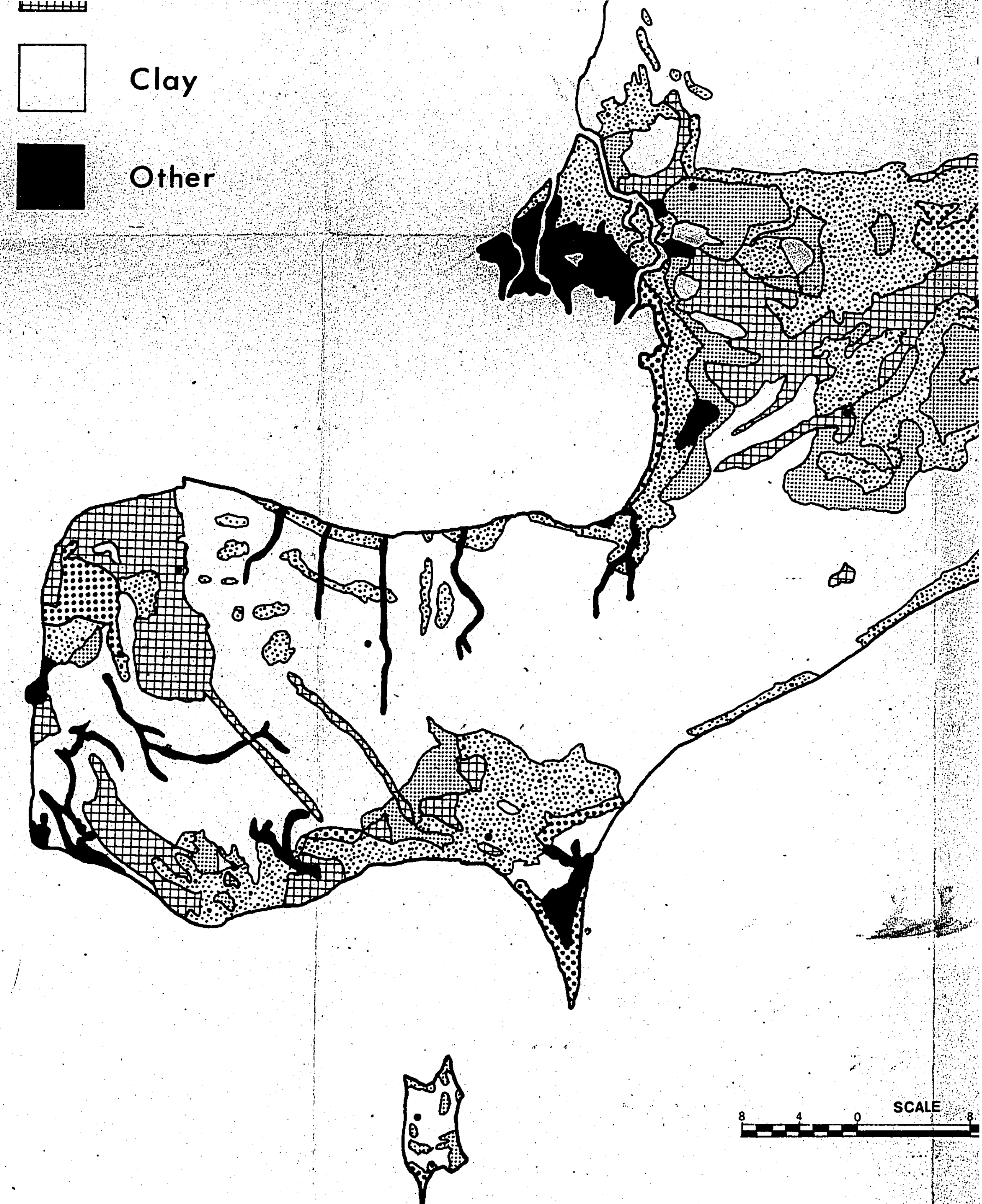
This reproduction is the best copy available.

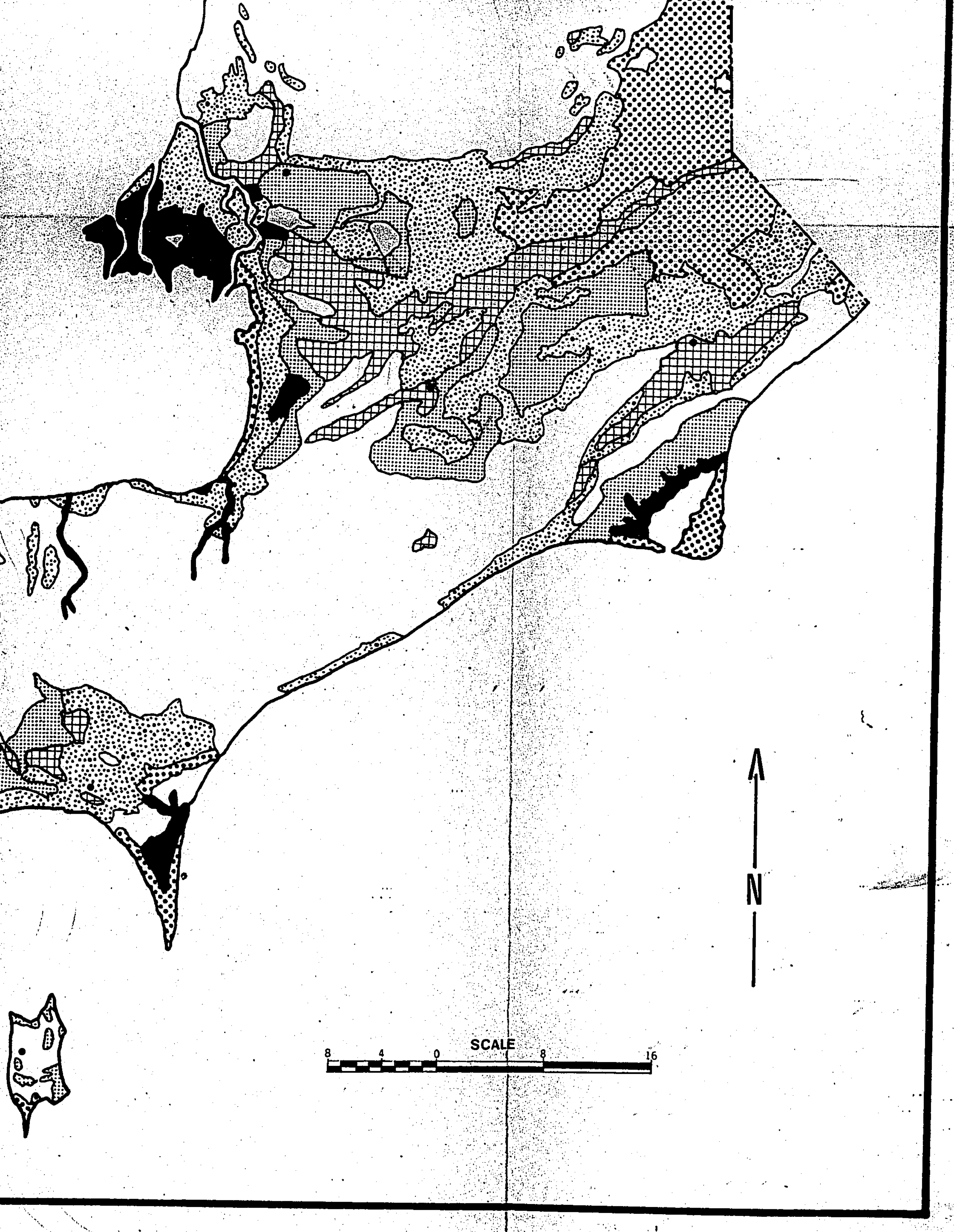
SOILS



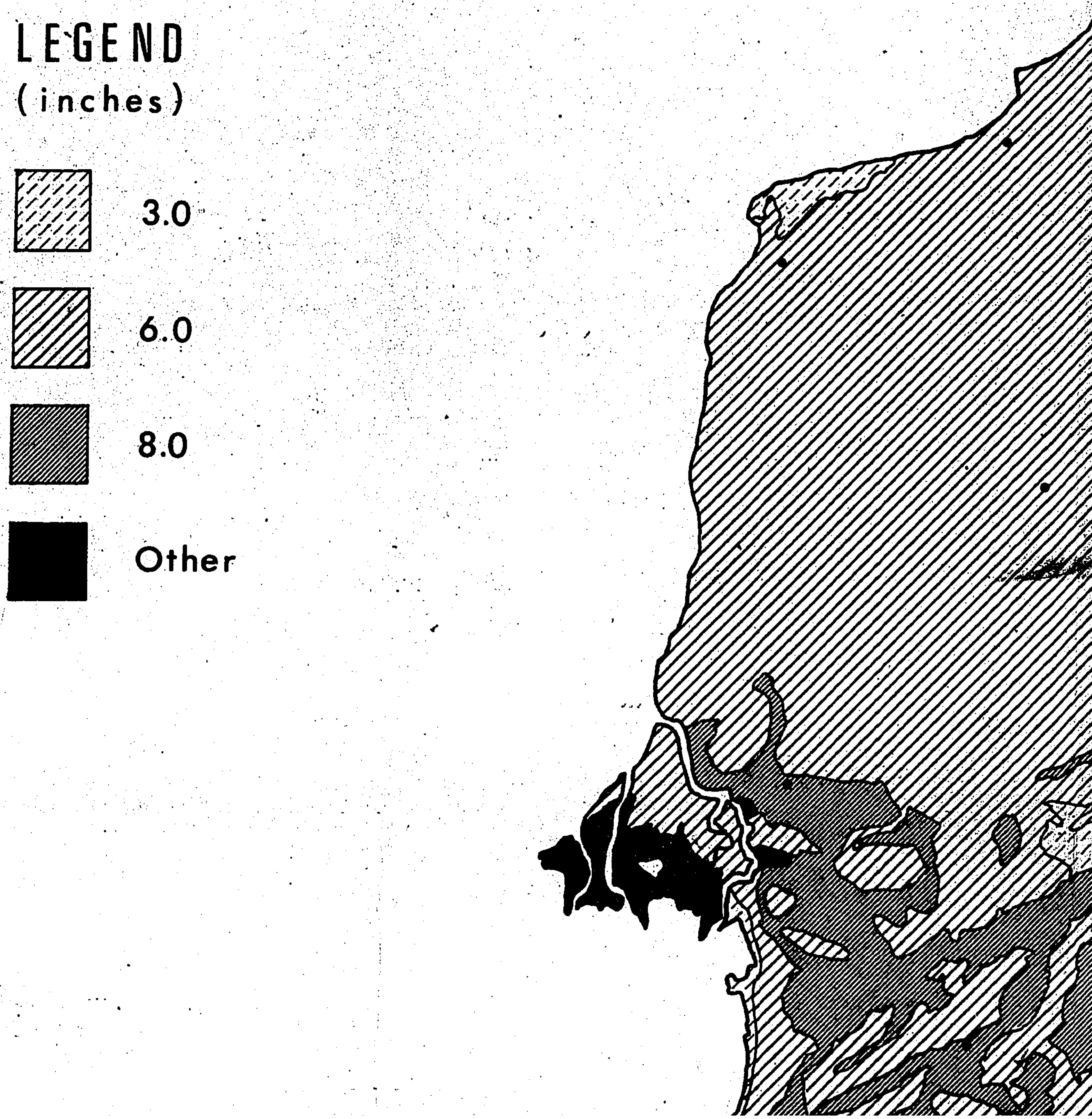
SOILS



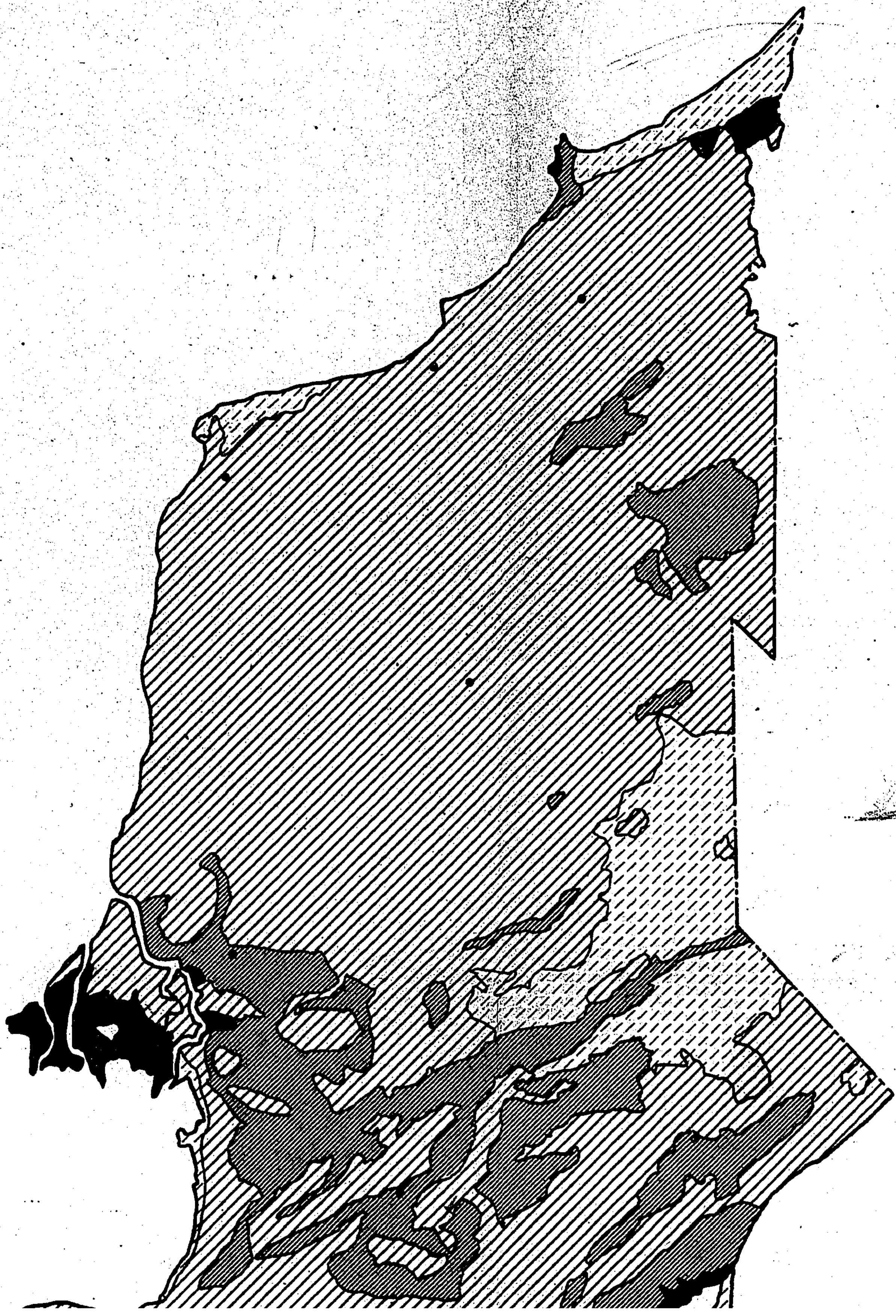

Clay
Other
SCALE
8
4
0
8

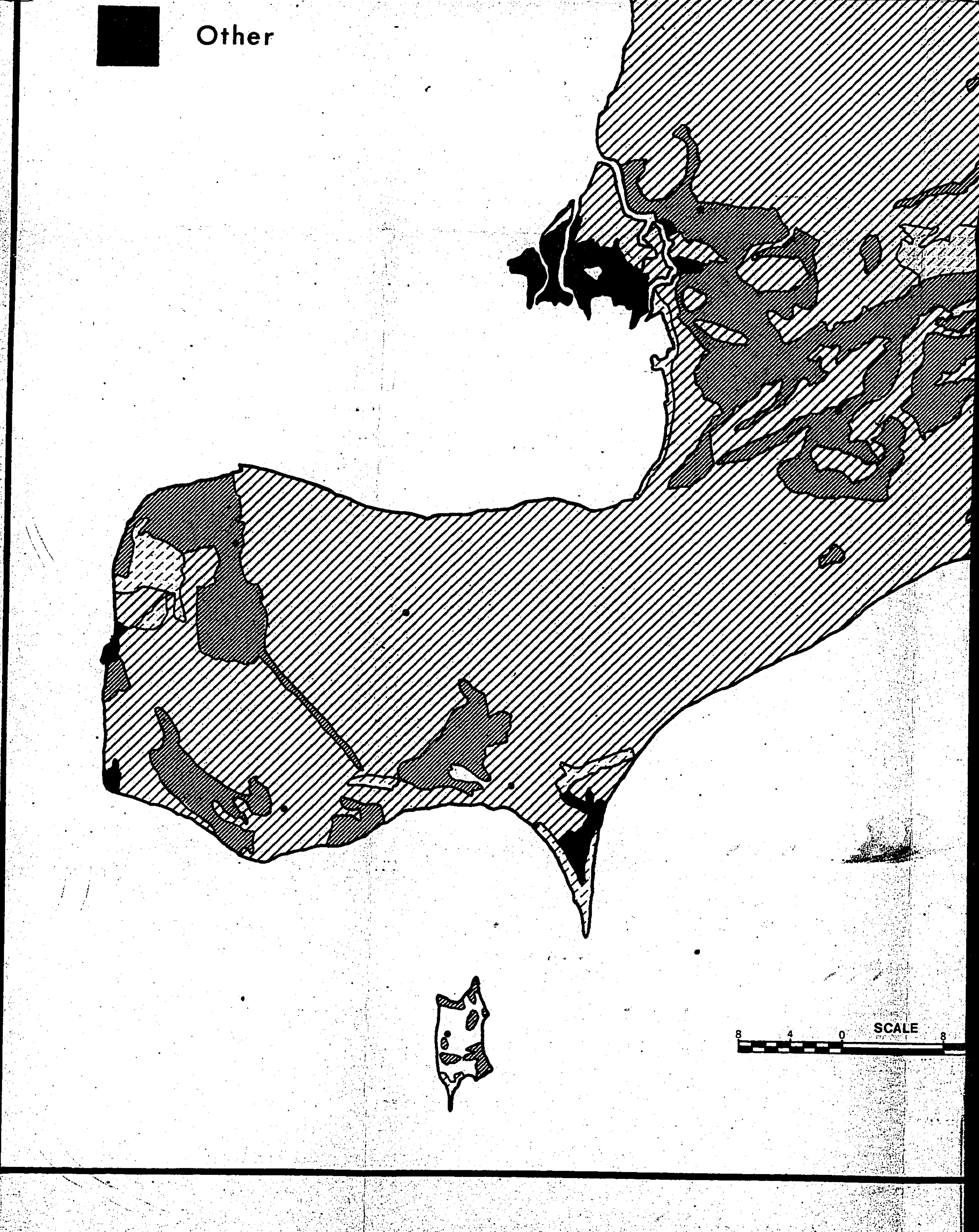

N
SCALE
8
4
0
8
16

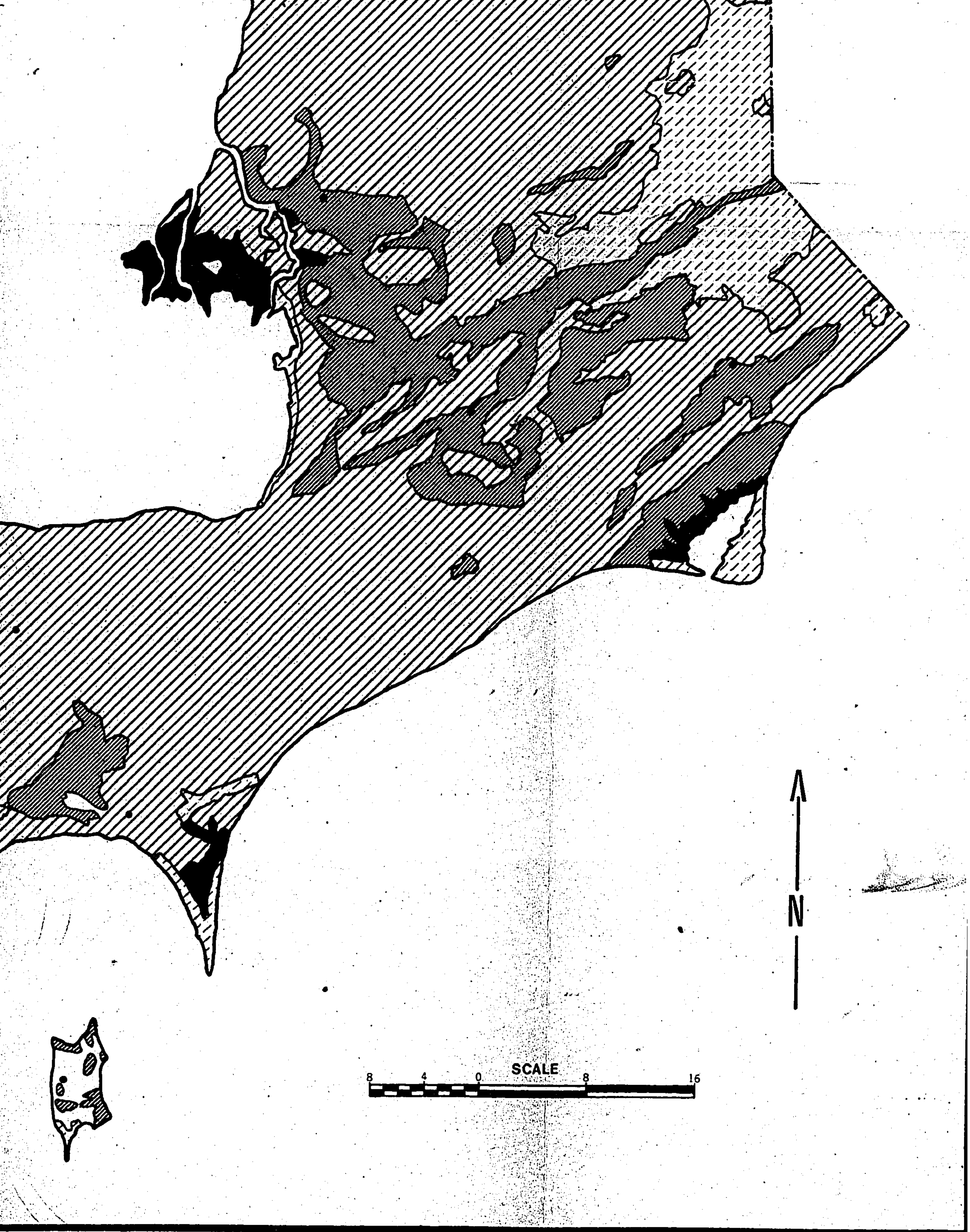
WATER HOLDING CA



HOLDING CAPACITIES




Other
SCALE
8
4
0
8


N
SCALE
8
4
0
8
16